METALS & ALLOYS

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The Magazine of Metallurgical Engineering

INCLUDING
CURRENT METALLURGICAL ABSTRACTS

SURFACE WORKINGS OF NEW JERSEY ZINC COMPANY AT FRANKLIN, N. J.

VOLUME 4 **SEPTEMBER 1933** NUMBER 9

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CURRENT METALLURGICAL ABSTRACTS

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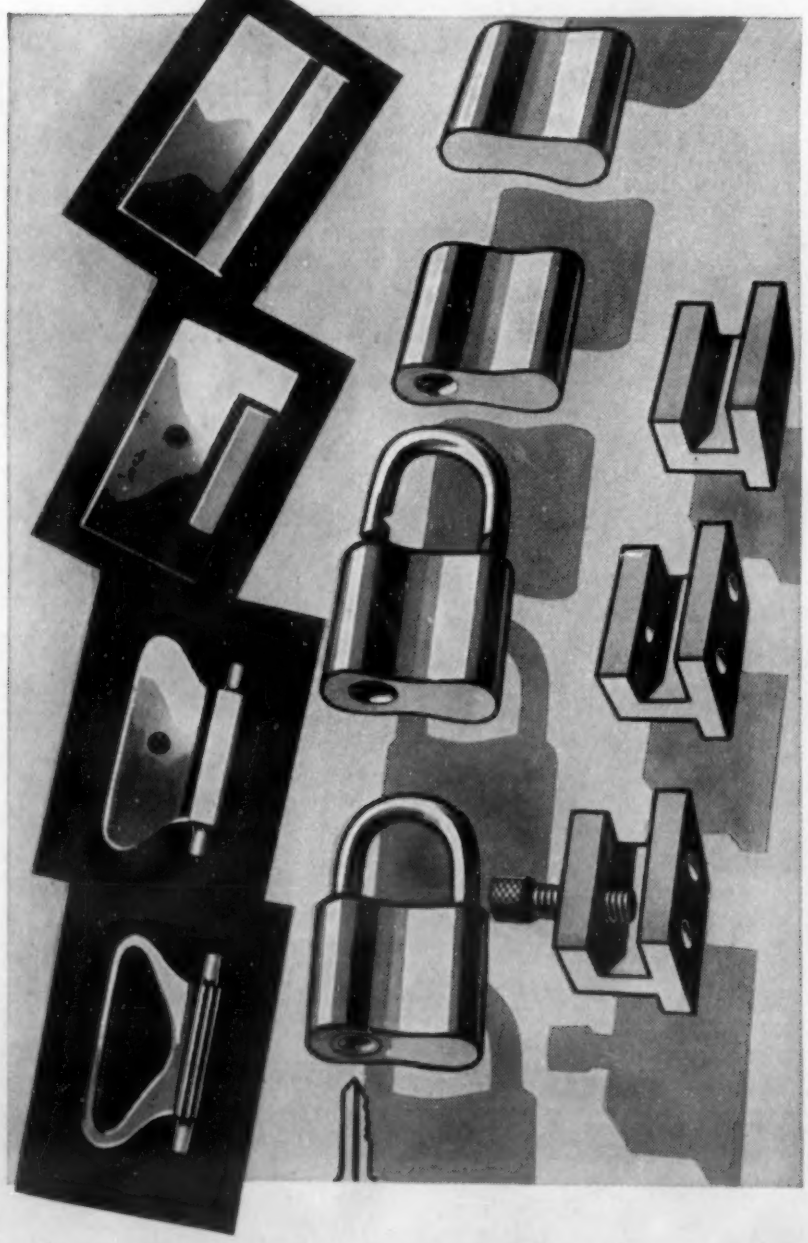

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HIGHLIGHTS

by H. W. GILLETT

A Bright Idea, Maybe!

Speaking of rotary furnaces, Zotos (page MA 300 R1) plans to rotate a furnace so fast that the metal forms a molten cylinder, held by centrifugal force, while the fuel burns inside, entirely surrounded by metal. Wonder if the energy required to rotate that fast wouldn't balance fuel saving! Also, what about that period of the heat before the metal melts?

Troubles That Come and Go, Nobody Knows Why

De Fleury (page MA 297 L1) ascribes these to piling up of impurities (poisons) in scrap at one period and of others (antidotes) at another. But aren't there lots of other factors in these mysterious troubles besides just the metal?

Remove Cold Worked Material

Wilhelm (page MA 296 R7) says hardening at cold-sheared edge of heavy plate is bad for impact or bending properties. The cold-worked material should be removed. This is just the same sort of thing found by Epstein (*Proceedings A.S.T.M.*, Vol. 32, Pt. 2, 1932) for punched holes in heavy angles.

To Avoid Corrosion Fatigue Use Compression?

To avoid corrosion fatigue, Ochs (page MA 286 L9) says one may use artificially produced compressive stresses. Kreissig (page MA 285 L8) seems to have about the same idea. Both Ochs, and Inglis and Lake (page MA 286 L2) report good fatigue resistance in rotary bending for nitrided steel, even under corrosion.

Platers Might Go In for Mushroom Culture

Fungus growths flourish in nickel and copper plating baths, according to Ollard (page MA 287 R2). Why not try to combine mushroom culture with plating if this should hold for edible varieties?

Brittle Welds

Because low carbon steel doesn't harden much on quenching welded joints are sometimes quenched. But Seferian (page MA 291 R5) points out that age-hardening can occur in many mild steels after such treatment, and claims that this may make the welds brittle in time though they may test all right at first.

Welders need a rest after Holidays and Pay Days

In a study of quality of product of individual welders made by Pohl (page MA 292 L7) no samples of their work were taken on the day after a Sunday, holiday, or pay day. Wonder if the quality would have been high or low had it been tested.

DO YOU want to know what metallurgical engineers are saying, the world over? Look in the Current Metallurgical Abstracts. Here are some of the points covered by authors whose articles are abstracted in this issue.

High Oxygen and Ductility

High oxygen occurs at bottom of ingots of converter steel and specimens from the bottom of the ingot show greater ductility according to Körber and Thanheiser (page MA 294 L4).

Better Cast Iron Ingot Molds

Cast iron ingot molds with 2% manganese last better in casting steel ingots, according to an anonymous German article (page MA 295 L4).

What About Allotropy?

Another blow is struck at the alleged allotropy of zinc and antimony. Sieglerschmidt (page MA 275 L7) finds that the impurities, not the zinc itself, cause the thermal expansion irregularities ascribed to allotropy by earlier metallurgists, while Schulze and Graf (page MA 275 L8) tell a similar story for antimony. Irregularities are, in this case, ascribed to the results of mechanical deformation. It takes a lot of telling to get corrections to errors across, once those errors have gotten into the text books.

Dope on Magnetic Hardening Cock-eyed

Corrections to the allegations of Herbert as to magnetic hardening are coming fast enough and soon enough after his postulates were put forth so that there is little danger that his point of view will be reflected in text books unless and until there is much more evidence of its correctness. At any rate Kussman & Wiester in Germany and Matuyama in Japan (page MA 291 L2 & 4) have experimented and state, in courteous and scientific language, that Herbert's dope is all cock-eyed.

Short Cycle Malleable

According to Söhnchen (page MA 291 L7) will result from proper composition (including low C) and by superheating and chill casting.

How Wide is Widely?

Metallbörse (page MA 277 L2) remarks that a magnesium piston alloy is "widely used," presumably referring to German practice. Wonder how wide "widely" is in tonnage or percentage.

12 Cylinder Alloys

The triangular diagram for ternary alloys is inadequate for more complex alloys and even the fourth dimension wouldn't help much in plotting properties against composition of lots of modern alloys for the trend seems to be toward 6 and 8 cylinder alloys at least these days. Paffenbarger et al (page MA 277 L5) discussing gold, silver, copper, platinum, palladium, zinc alloys for dentistry while Illium (Aug. issue, page MA 242 L1) contains nickel, chromium, copper, iron, tungsten, molybdenum and silicon. After all, even a commercial "carbon" steel will have besides iron, carbon, manganese, silicon, sulphur and phosphorus also nickel, copper, arsenic, oxygen, nitrogen and hydrogen to say nothing of a few other things in tiny traces. Sometimes this "engine" may not work just right because we insist on timing it as a 6 cylinder only when it really has 12 or more.

Tell Your Dentist About This

A "technic alloy" sold to budding dentists so they can practice up on casting gold inlays, etc., by handling an alloy that acts like gold but is cheaper, contained some 88 Cu, 10 Al, 2 Sn and sold for $5.00 an ounce, say Easton and Ray (page MA 276 R5). It's a good thing that modern dental training includes some metallurgy.

Austenitic Manganese Steel

John Howe Hall (page MA 278 L2) says you can make just as good austenitic manganese steel from the Bessemer or the open hearth as from the electric furnace.

Growth of Cast Iron

Scheil (page MA 284 L1) says most laboratory tests that measure length changes on thin samples make growth out to be worse than it is in practice in heavy section.

Endurance of Cast Iron

Heller (page MA 285 L3) summarizes it from 56 references.

Precipitation Hardening is Everywhere

In 18-8 it comes from carbon and Reggiore (page MA 290 R9) shows that Italian metallurgists like those of other countries are trying to prevent precipitation by use of molybdenum, copper, titanium, vanadium, etc. But Chevenard (page MA 291 L4) wants to give age hardening properties to a 35 nickel 10 chromium austenitic alloy by use of 3½ aluminum. High aluminum enters into a few commercial heat resistant alloys in the U. S. but few appear to know how it acts, they seem to figure, from practical results that aluminum is good for what ails it, without much definite effort to seek out just what its effects are and how to control them.

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Editorial Comment

Government Metallurgical Research Under New Deal

THE METALLURGICAL research of our Government laboratories is being sharply curtailed, since it is under the "ordinary" budget on which campaign promises for retrenchment are in process of fulfillment. This may be hailed with joy, with lamentations, or with equanimity, depending on whether one belongs to the small group that sees no good in anything done by Government action, to the other small group that thinks anything it reads in a Government bulletin is necessarily the last word, or to the larger group which realizes that the Government scientists are human and liable to error, but by virtue of their position and environment have no axe to grind and whole-heartedly seek the facts and state them as they see them.

Many problems can be handled no better, if as well, in a Government laboratory than outside it. However, there are problems requiring primarily continuity of effort over a period of years and a complete lack of bias, and secondarily, reasonable technical ability, that can be tackled more effectively by a Government group than by any other. On the whole, Government research is less affected by "up today and down tomorrow" commercial handicaps than is private effort, and can do its most effective work on the "long pull" type of problem.

But in the course of time there are likely to creep into a long-term program, and to stay there because there is always one thing more to try, projects that are not of very great importance or on which the economic condition has passed that once made them important. The necessity for drastic Government retrenchment forces a clean-cut decision as to the relative importance of the work in hand and in the long run the operation will improve the patient. Like all operations, it has unpleasant features. There are many employees of long standing who have supposed their Civil Service status gave them a security of employment that compensated for the lower salaries in Government than in commercial service in ordinary times, and hence, passed up opportunities to take commercial employment, who now find themselves forced out of the service. And the criteria of retention or separation are highly artificial and red-tapish, so that separation is no reflection on the ability of the people dropped. Most of them will be rather promptly absorbed into industry unless we drop into another depression, so we need not linger on that dark personal side of the picture.

Since the curtailment of funds forces a decision by the management of each Government laboratory as to what it is going to do for the public good in the immediate future, these decisions and plans are of interest to all who are concerned with metallurgical research and its results. While these men guide the expenditure of but a tiny fraction of a mill of our tax dollar, it is a fraction from which the public will get a worth while return some day if it is wisely expended.

The largest Government metallurgical research laboratories are those of the Bureau of Standards and Bureau of Mines. Important metallurgical work also goes on at some of the Army and Navy laboratories, on whose plans we hope to be able to comment at a later date. The metallurgical work of Mines, it will be recalled, relates primarily to the problems encountered in mining, milling, smelting and melting, while that of Standards relates chiefly to control of properties in the alloying and processing of the metals on down to the finished product. Roughly, Mines deals with chemical metallurgy and Standards with physical metallurgy.

In an article in this issue, Dean reports in considerable detail on the plans of Mines for its metallurgical work. As that article speaks for itself, little editorial comment is called for. On the whole, it is evident that projects already in hand will be brought to a reportable stage where possible in order to salvage the investment made in past work. The list of projects cited seems rather extensive for effective continued attack with a much reduced personnel, but the plan seems to be to concentrate, when some of the present projects can be concluded, on the type of work that calls for continued effort over a period of years, and which industry is not likely to take up for itself.

No provision seems to be made for effort along the lines of the "physical chemistry of steel making" in which field the Bureau of Mines formerly did much good work, and received much credit therefor, the assumption having been made, long before the present emergency, that the Bureau had done its share in that field, and that further work would be left to industry. The important work on blast furnace operation also seems to be curtailed. The wisdom of the transference of effort from these fields of present problems to that of direct reduction is a matter of some dispute, but time will tell whether a wise decision was made.

(Continued on page 136)

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HEATING ELEMENTS

HEAT-RESISTING CHROMIUM-NICKEL-IRON ALLOYS

FOR FURNACE CONSTRUCTION

By L. J. Stanbery*

Part I. Load Carrying Ability

THE DECISION as to allowable design stresses for high temperature service of metals is one which each design engineer must make for himself, on the basis of his own knowledge of the properties of the materials he is to use, and of the requirements of the particular structure being designed. He must decide on his own factor of safety and he cannot sidestep the responsibility for his own choice on the basis of what others have done.

Yet acquaintance with what others have found satisfactory in practice will be very helpful, whether he agrees with them, whether he prefers to take a more conservative attitude, or, on the other hand, dares to cut his sections down or raise his loads.

It should be pointed out that the design values herein refer to heat-resisting alloys for furnace use. They would be wholly inapplicable for turbine design and are not advocated by the author for any other service than that of furnaces.

It is of interest to note that actual creep data are not available for 1800°-2000° F. Strong as is the engineer's desire to avoid empiricism, it is a sad fact that design of heat resisting furnace parts for use at such temperatures still rests primarily on an empirical basis. This article shows clearly how scanty are the precise data on long-time load-carrying ability of furnace alloys determined under conditions where loads and temperatures can be really controlled. So far most of the information has been obtained by trying an alloy in service and seeing how it works. This is all right when it does work, expensive when it does not, and a rather inadequate way of making rapid progress in the development of new and better alloys.

Speaking primarily of alloys for relatively low temperature, Duff† says: "In one sense the alloy producers have the easiest part of the game. Very few of them have first-hand information as to the data that are printed in their catalogues and pamphlets and woe be to the consumer who accepts in good faith all he reads. Many of the producers have 'pet' alloys that absolutely do not live up to their advertised qualifications."

This appears to hold for the furnace alloys as well. And on the other hand, it seems probable that some producers are so conservative that they are not giving some of their alloys credit for their real load-carrying ability at very high temperatures.

The concluding section dealing with the selection of alloys for specific conditions of use will be published in the next issue.

—H. W. Gillett

†R. L. Duff, Metallurgy of Refining Equipment, *Refiner & Natural Gasoline Manufacturer*, Vol. 12, April, 1933, pages 110-114.

CERTAIN parts for heat treating furnaces, supports for tubes in oil stills, etc., that must operate at say 1200°-2100°F., must needs be made of heat-resisting alloys, and are generally made from alloys of the Ni-Cr-Fe series, both for resistance to oxidation, and for load carrying ability.

At such temperatures the strength of the alloys falls off with increase in temperature with amazing and disconcerting rapidity.

The designer of such parts from costly alloys must conserve material on the one hand and keep the part in operating condition for a reasonable period on the other. In such services, while the material is costly, a failure is costly too. The designer must be conservative enough in his design to insure the economies of long life, but as daring as possible to avoid an extravagant first cost. That is, this is a typical metallurgical engineering problem.

The metallurgical engineer, who must select the alloy for a given service and appraise its long-time load-carrying ability in that service, wishes to do so on the basis of engineering knowledge rather than solely on that of cut-and-try experience. He looks for data on load-carrying ability in terms of pounds per square inch; what he finds is appalling. Pilling and Worthington[1] close their discussion of the high-temperature properties of Fe-Cr-Ni alloys by tabulating the safe loads, or allowable fiber stresses used by different designers. For an alloy of 28% Cr, 10% Ni, 0.40% C, at 1600°F., one designer uses 3800 lbs./in.^{2}, another 650 lbs./in.^{2} For one of 17% Cr, 36% Ni, 0.50% C, one designer uses 1250 lbs./in.^{2}, another 140 lbs./in.^{2} Differences of 600 to 900% in the estimate of load-carrying ability mean something when these are translated into terms of first cost on the one hand and risk of failure on the other. As McCormick[2] phrases it, such differences indicate "misinformation or misrepresentation," presumably the former.

Until sufficient information is available to tell which figures are correct, and why, the engineer must use his judgment. Furnaces have to be built and the materials and dimensions of the parts have to be settled upon without waiting for more information.

These alloys are, in general, of the austenitic type and the temperatures in question are above the strain-hardening range. Short-time tensile tests at these temperatures give values that may be helpful in evaluating resistance to momentary overload, but vastly over-valuate the load-carrying ability over long periods. Some of the guesses at safe loads have been made on some such basis as allowing 5 or 10% of the short-time tensile strength. Somewhat more prolonged loading at loads that produce failure, such as were used by Jenkins and coworkers,[3] throws further light on the problem, but does not solve it, for the alloys can fail by sagging out of shape and the parts are ruined long before they have stretched clear to fracture. One can design only for failure, not for its prevention, on the basis of such data alone. Some designers have based their guesses on some such ratio as a quarter of the short-time proportional limit, but

[1] N. B. Pilling & R. Worthington. The Effect of Temperature on Some Properties of Fe-Cr-Ni Alloys. *Symposium on Effect of Temperature on the Properties of Metals, American Society for Testing Materials—American Society of Mechanical Engineers*, 1931, pages 495-546. Compare also Report of Committee A 10 on Fe-Cr, Fe-Cr-Ni and Related Alloys, *Proceedings American Society for Testing Materials*, Vol. 30, Part I, 1930, page 255 and Appendix IIIa.

*Consulting Metallurgist, Toledo, Ohio.

[2] G. C. McCormick. Discussion, *Symposium on Effect of Temperature on Properties of Metals, American Society for Testing Materials—American Society of Mechanical Engineers*, 1931, pages 554-556.

[3] C. H. M. Jenkins, H. J. Tapsell, C. R. Austin & W. P. Rees. Some Alloys for Use at High Temperatures. *Journal Iron & Steel Institute*, Vol. 121, 1930, pages 237-304.

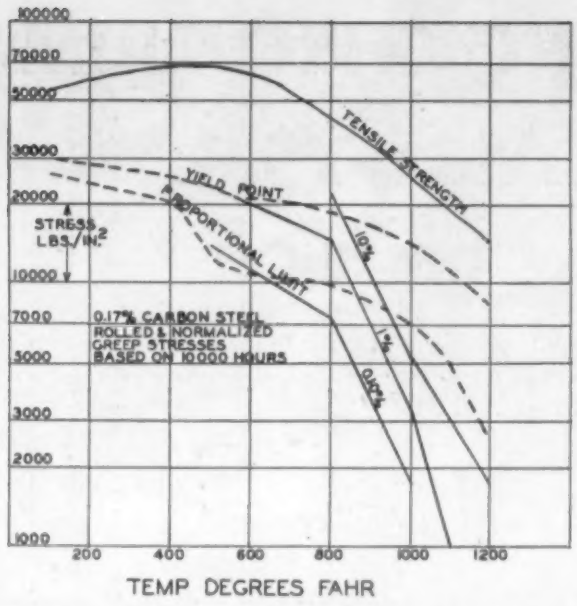


Fig. 1. Comparison of Short-Time Tests and Creep Tests (Kanter & Spring)

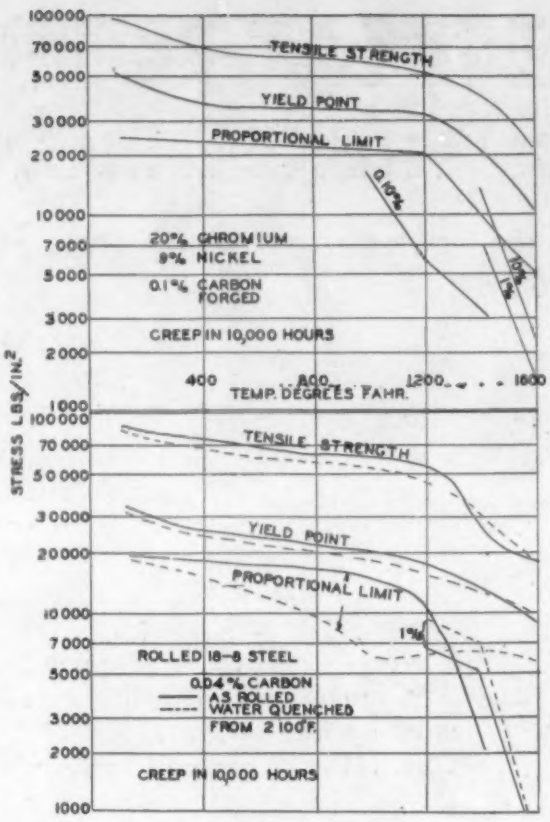


Fig. 2. (Kanter & Spring)

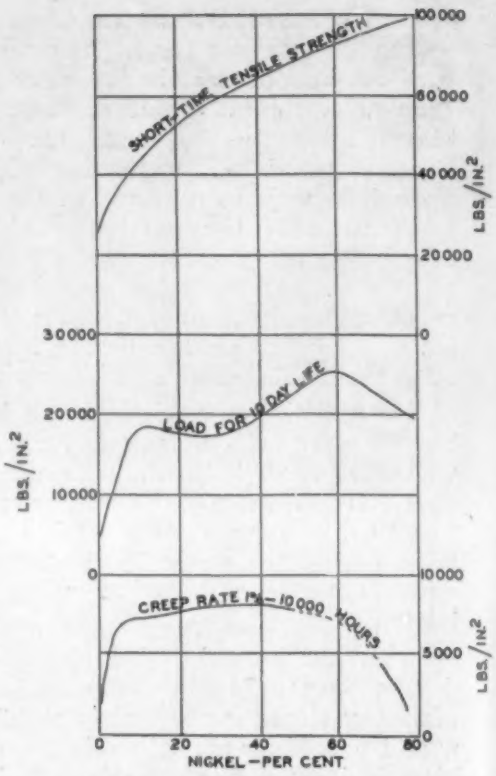


Fig. 3. Effect of Nickel Content on Strength Properties of 20% Chromium-Iron Alloys at 1200° F. (Pilling & Worthington)

there appears to be no true proportional limit above the strain-hardening range of temperature, the values varying with the sensitivity of the equipment used. Indeed the Joint Research Committee of the A.S.T.M.-A.S.M.E. on Effect of Temperature on the Properties of Metals[4] does not include any methods for determining proportional limit in the Code for Short-Time High Temperature Tensile Testing, both because of the difficulties of determining it at high temperatures and because of lack of any proven correlation with the long-time load-carrying ability.

Since the alloys in question, at the temperatures in question, are considered to be continually stretching, the design problem is to determine the load which will not produce more than a certain allowable degree of deformation in the period of a satisfactory life for the part in question. That is, the problem has to be expressed and answered in terms of rate of deformation, i.e., creep.

The wide discrepancies among the tales told by short-time and proportional limit and creep tests are shown for a carbon steel by Fig. 1, after Kanter and Spring and taken from Brown's 1931 discussion,[5] while Fig. 2, also after Kanter and Spring, taken from Pilling and Worthington[1] shows the same thing for the Ni-Cr-Fe alloys. Fig. 3, after Pilling and Worthington[1] shows that the loads producing failure in 10 days do not correlate with creep resistance.

We must then look for true creep data on the type of alloys in question. How much do we really know about load-carrying ability of Cr-Ni-Fe heat-resisting alloys at high temperatures? Lives of 10,000 to 20,000 hours are desired in the type of service we are considering.

Within this period, creep of 1% is permissible in the furnace parts and even 5% is often bearable. Design is then usually on a basis of a creep rate of 1% in 10,000 hours. In still tubes, on account of hazard to life, and of fire, undue deformation is taken as a sign of danger. 1% in 10,000 hours is the usual design criterion for material that stretches considerably before giving way, and 1% in 100,000 hours for that which tends to give way without warning. More liberal creep rates may be allowed by some designers, while others use a factor of safety on these values, but as a common denominator, creep rates of 1% in 10,000 or 100,000 hours are spoken of. Since actual determinations of creep usually run from 500 to 2000 hours, the rates observed are actually more properly called 0.10% or 0.01% in 1000 hours.

To determine these creep rates, one might measure up material discarded from service, but the actual maximum temperature reached in a coked tube or a "runaway" furnace is too hazily known to give accurate information. The rate of creep increases hugely as temperature is increased, so to evaluate competing materials with accuracy, laboratory creep tests, in which temperature is most accurately controlled, are necessary. An occasional engineer decries creep tests because the data from the laboratory often seem none too concordant, but most designers utilize what creep data there are and wish there were more.

The designer is, indeed, more insistent for creep data than the metallurgist is. If we eliminate all the near-information based on short-time or accelerated tests, because it is likely to be misinformation for the designer, and rely solely on actual creep tests, what facts do we really have about load-carrying ability?

The data are chiefly in English and are in publications available to most metallurgists. With the exception of a recent paper by Tucker and Sinclair[6] the information has been collected in the last Symposium held by the Joint High Temperature Committee of the A.S.T.M. and A.S.M.E.[7] Outside of this, the publications by Norton,[8] by French and coworkers,[9,10] and the tables in the appendix to a report of A.S.T.M. Committee B4,[11] contain

[4]Committee Report, Appendix. *Preprint* No. 23, *American Society for Testing Materials*, 1933, 34 pages.

[5]R. S. Brown. Discussion, *Symposium on Effect of Temperature on Properties of Metals, American Society for Testing Materials—American Society of Mechanical Engineers*, 1931, page 95.

[6]W. A. Tucker & S. G. Sinclair. Creep and Structural Stability of Ni-Cr-Fe Alloys at 1600°F. *Bureau of Standards Journal of Research*, Vol. 10, 1933, pages 852-862.

[7]*Symposium on Effect of Temperature on Metals. American Society for Testing Materials-American Society of Mechanical Engineers*, 1931, 829 pages.

[8]F. H. Norton. Creep of Steels at High Temperatures. McGraw-Hill Book Company, New York, 1929.

[9]H. J. French, W. Kahlbaum & A. A. Peterson. Flow Characteristics of Special Fe-Ni-Cr Alloys and Some Steels at Elevated Temperatures. *Bureau of Standards Journal of Research*, Vol. 5, 1930, page 125.

[10]H. J. French, H. C. Cross & A. A. Peterson. Creep in Five Steels at Different Temperatures. *Bureau of Standards Technologic Paper* No. 362, 33 pages.

[11]Report of Committee B4. Tables of Chemical Compositions, Physical and Mechanical Properties and Corrosion-Resistant Properties of Corrosion-Resistant and Heat-Resistant Alloys. *Proceedings American Society for Testing Materials*, Vol. 30, Part I, 1930, Plates V to XV.

Cast Alloy Elements, Walking-Beam Pair Heater, Suspended Type (Courtesy of the Standard Alloy Company and the Surface Combustion Corporation)

the most important data. This material has not been assembled from the point of view from which we wish to discuss it.

It is logical to consider the problem primarily from the point of view of the composition of the alloys. The heat-resistant group of alloys is built upon the ternary system Cr-Ni-Fe as a basis, the Cr supplying resistance to attack by O and S gases and the Ni providing a means of securing the austenitic structure which has higher load-carrying ability at high temperatures than the ferritic one.

Faith in this group of alloys doubtless arose from the behavior of the Ni-Cr resistor elements in electric resistor furnaces which operate for long periods undamaged by oxidation, although they do not often carry appreciable loads. That other things than the composition alone govern the high temperature life and high temperature properties is evident from the history of the 80% Ni, 20% Cr, resistor alloy, which, without change from that nominal composition, has been vastly improved in recent years by better melting and processing methods. Smithells, Williams and Avery[12] show very marked differences in sagging of cantilever specimens made of different grades of Ni, ascribing the difference to the presence or absence of minute amounts of S. Deoxidation methods, amount of Mn and Si and especially of C also play an important part. Ni-Cr-Fe alloys are not those of 3 elements only, but of at least 6, i.e., they are Cr-Ni-Fe-C-Mn-Si alloys. And to this combination there is justification for the addition of Al, Mo, W, Ti and possibly other metals in small amounts as seasoning for the Irish Stew.

Iron is present not merely as a diluent and cheapener, but also because the Cr-Ni-Fe alloys have higher load-carrying ability with scarcely any loss of oxidation resistance, than the Cr-Ni alloys. C is there, not as an adventitious impurity in the Fe and in the ferro-chromium, but also, especially in the case of castings, for its strengthening effect. It introduces important complications from the point of view of stability, due to the deposition of carbides in the grain boundary at certain high ranges of temperature.

Notwithstanding that the alloys are highly complex, it is logical to consider them first as to composition in respect to Cr, Ni and Fe, and to go from there, when information is available, to the effect of incidental or added elements.

It is not necessary to consider the plain Fe-Ni alloys since they do not have enough resistance to oxidation to be serviceable for high temperature uses.

The plain Cr-Fe alloys may be considered first, not only because the Cr is responsible for the adherent, flexible pellicle of oxide that protects the heat-resistant alloys, but also because this group is essentially ferritic, and a decidedly different "breed of cats" from the ternary austenitic alloys that form the bulk of the heat-resistant group. According to Moneypenny[13] 15% Cr must be present for oxidation resistance at 1500°F., 20% at 1800°F., 25% at 2000°F., and 30% at 2100°F., and that these figures are not altered by the presence of 10% Ni. 20% or more of Ni increases the resistance, while 1 to 2% Si or Al increase it markedly and 4% W does not alter it.

The high temperature heat-resistant alloys therefore carry more than 10%, usually 15 to 20% or even 25% Cr. One industrial alloy, "4-6% Cr" used for cracking-still tubes and the like, below 1300° F., has a lower Cr content, but the Cr is used for a degree of resistance to corrosion by the crude S-bearing oil and for some small increase in load-carrying ability over plain C steel rather than for oxidation resistance, which it does not possess in marked degree. Few creep values on the 5% Cr tube steel have been published, though considerable work has been done. This steel is often bolstered up by the addition of 0.50% Mo or 1.0% W, with the tendency toward using the former. The appraisal of available but unpublished data has led M. R. Whitney of the M. W. Kellogg Company to the conclusion as to load-carrying ability of these alloys given in Table 1 and shown in curves 2 and 3 of Fig. 4 in comparison with his curves for C steel, curve 1. Dixon[14] appraises the 5% Cr steel as having

[12] C. J. Smithells, S. V. Williams & J. W. Avery. Laboratory Experiments on High Temperature Resistance Alloys. *Journal Institute of Metals*, Vol. 40, 1928, page 269, discussion page 291. See also *Symposium on Effect of Temperature on Properties of Metals, American Society for Testing Materials-American Society of Mechanical Engineers*, 1931, page 521, Fig. 18.

[13] J. H. G. Moneypenny. Stainless Iron and Steel. 2nd Edition. John Wiley & Sons, New York, 1931.

[14] E. S. Dixon. *Symposium on Effect of Temperature on Properties of Metals, American Society for Testing Materials-American Society of Mechanical Engineers*, 1931, page 99.

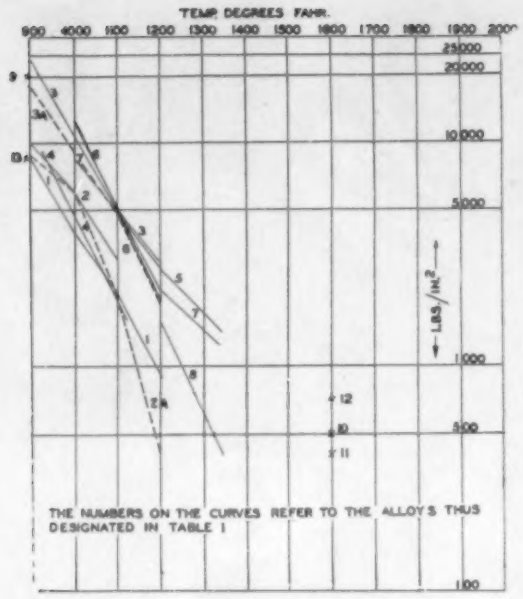


Fig. 4.

Table 1. Load Capacity of Plain Cr-Fe Alloys (Plotted on Fig. 4)

		Load Capacity in lbs./in.² at							
	Alloys	800°F.	900°F.	1000°F.	1100°F.	1200°F.	1350°F.	1600°F.	Remarks
1	Tube Steel (low C)		8600	4000	2100	900			Safe load
2	Tube Steel (5% Cr)		10000	6000	3000				Safe load
2a	Tube Steel (5% Cr)[g]		9200	6000	2000	840			1%—10,000 hrs.
3	5% Cr, ½% Mo (or 1% W)		24000	11000	5000	3000			1%—10,000 hrs.
3a	5% Cr, ½% Mo[g]		18000	9200	4800	1800			1%—10,000 hrs.
4	12% Cr[a]		(930° 9200)		(1110° 1800)				1%—10,000 hrs.
5	12% Cr, 0.09% C[b] (H)				5000	2600	1400		1%—10,000 hrs.
6	13% Cr, 0.11% C[b] (F)			13000	5200	2100			1%—10,000 hrs.
7	17.6% Cr, 0.10% C[b] (G)			8500	5300	2100	1200		1%—10,000 hrs.
8	26.9% Cr, 0.20% C[b] (J)					1600	400		1%—10,000 hrs.
9	18% Cr[c]	25000	20000						1%—10,000 hrs.
10	17.5% Cr, 0.50% C[d] (Cast)							500	1%—10,000 hrs.
11	27.5% Cr, 2% Ni, 0.19% C[e] (Cast) (73)							400	1%—10,000 hrs.
12	55.8% Cr, 0.8% Ni, 0.37% C[e] (Cast) (74)							700	1%—10,000 hrs.
13	20.5% Cr, 0.28% C, 1% Cu[f] (Rolled)		8500						1%— 1,000 hrs.

[a]Tapsell. "Creep of Metals," page 228.
[b]Norton. "Creep of Steels at High Temperatures."
[c]Duff. (Private communication.)
[d]A.S.T.M. Committee B4 Appendix 1930.[11]
[e]Tucker & Sinclair Report.[6]
[f]French, Cross & Peterson[10]. Alloy "A-340".
[g]Norton, quoted by Newell. Alloy Steel Tubes for Refinery Service, *Refiner & Natural Gasoline Manufacturer*, Vol. 12, Apr. 1933, pages 122-131. (These later data are shown by the dotted lines 2A and 3A, Fig. 4.)

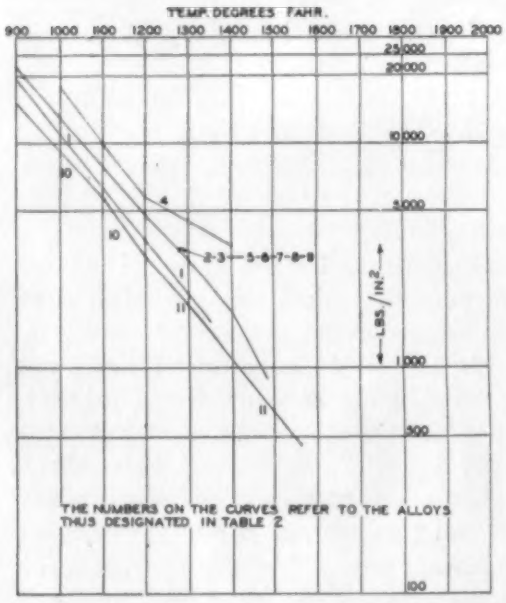


Fig. 5.

Table 2. Load Capacity of Chromium-Nickel (18-8) Alloys (Plotted in Fig. 5)

		Load Capacity in lbs./in.² at							
	Alloys	900°F.	1000°F.	1100°F.	1200°F.	1300°F.	1400°F.	1500°F.	Remarks
1	18% Cr, 9% Ni, 0.05% C[a]	20000	12000			(1350° 1600)			1%—100,000 hrs.
2	18% Cr, 8.5% Ni, 0.07% C[b]	20000	15000	8500	5500	3500			1%—100,000 hrs.
3	18% Cr, 8.5% Ni, 0.12% C[c]	(930° 16000)	(1020° 10500)	(1110° 6500)	4300	(1290° 2500)	(1330° 1800)		1%—100,000 hrs.
4	19.8% Cr, 9.4% Ni, 0.10% C[d]		18000		5700		3500		1%—100,000 hrs.
5	18% Cr, 10.7% Ni, 0.075% C[e]	25000	15000	8000	5000	3000			1%—100,000 hrs.
6	18% Cr, 8% Ni, 0.15% C[f]		15200	8500	5400	3400	1900	900	1%—100,000 hrs.
7	20.2% Cr, 7% Ni, 0.43% C, 0.23% V, 0.6% W[g]		19000		5000				1%—100,000 hrs.
8	18% Cr, 8% Ni, 0.09% C[h]	19500	15000	8000	5500	(1380° 2100)		750	1%—100,000 hrs.
9	18% Cr, 8% Ni[i]		15000	8000	5000	3000	1800	200	Safe Load
10	18% Cr, 8% Ni[j]	16000	10000			2000			Allowable Stress
11	18% Cr, 8% Ni[k]			(1110° 5700)		(1290° 2100)	(1470° 850)	(1560° 470)	
12	18% Cr, 8% Ni, 0.07% C[l]	18000	11500	7100	4250	2200	1000		1%—100,000 hrs.

[a]Norton. *Symposium on the Effect of Temperature on the Properties of Metals, American Society for Testing Materials-American Society of Mechanical Engineers*, 1931, page 510, Fig. 9, Curve 4.
[b]*Symposium on the Effect of Temperature on the Properties of Metals, American Society for Testing Materials-American Society of Mechanical Engineers*, 1931, page 474, Table VI.
[c]Babcock & Wilcox Tube Company.
[d]Kanter & Spring. Some Long-time Tension Tests of Steel at Elevated Temperatures. *Proceedings American Society for Testing Materials*, Vol. 30, Part I, page 110.
[e]Duff, *Symposium on the Effect of Temperature on the Properties of Metals, American Society for Testing Materials-American Society of Mechanical Engineers*, 1931, page 510, Curve 8.
[f]*Symposium on the Effect of Temperature on the Properties of Metals, American Society for Testing Materials-American Society of Mechanical Engineers*, 1931, page 474, Table VI.
[g]Norton. Creep of Steels at High Temperatures. McGraw-Hill Book Co., New York, 1930. Alloy "D".
[h]Norton. Creep of Steels at High Temperatures. McGraw-Hill Book Co., New York, 1930. Alloy "E".
[i]Kice. Rustless Steels Employed in Fan Construction. *Iron Age*, Vol. 131, 1933, page 507.
[j]*Symposium on the Effect of Temperature on the Properties of Metals, American Society for Testing Materials-American Society of Mechanical Engineers*, 1931, page 76, Table II, Refiner "F".
[k]Rohn.[16] Das Verhalten metallischer Werkstoffe bei Temperaturen bei denen auch nach kleiner Verformung Rekristallisation eintritt. *International Association for Testing Materials*, Zurich Meeting, 1931, Vol. 1, 1932, pages 177-182; abstract, *Metals & Alloys*, Vol. 4, 1933, page MA 197.
[l]Norton, quoted by Newell. Alloy Steel Tubes for Refinery Service. *Refiner & Natural Gasoline Manufacturer*, Vol. 12, 1933, pages 122-131. (These data, later than those of curve 2 for the same composition, are not plotted on Fig. 5, but lie near curve 1.)

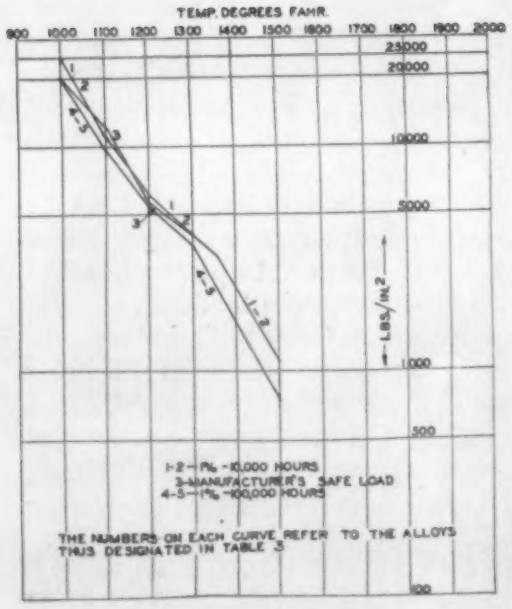


Fig. 6.

Table 3. Load Capacity of "Reversed" (18-8) Alloys (Plotted on Fig. 6)

		Load Capacity in lbs./in.² at							
	Alloy	1000°F.	1100°F.	1200°F.	1300°F.	1350°F.	1400°F.	1500°F.	Remarks
1	Cr 6.4%, Ni 19%, C 0.14%[a]	25000	11000	6000		3200		1100	1%—10,000 hrs.
2	Cr 8%, Ni 20%, C 0.20%[b]	25000	11800	6000	4000			1100	1%—10,000 hrs.
3	Cr 8%, Ni 20%, C 0.40%[c]	20500	11800	5000	4000				1%—10,000 hrs.
4	Cr 6.4%, Ni 19%, C 0.14%[a]	20000	9500	5500			2800	750	1%—100,000 hrs.
5	Cr 8%, Ni 20%, C 0.20%[b]	20000	9500	5500	3600			750	1%—100,000 hrs.

[a]Norton. Creep of Steels at High Temperatures, Alloy "B".
[b]Strauss. Castings of Corrosion-Resisting Steels, Alloy 4, Table I, page 182, *Symposium on Steel Castings, A.S.T.M.-A.F.A.*, 1932, pages 175-199.
[c]A.S.T.M. Committee B4, Appendix 1930,[11] Cyclops 17.

Table 4. Load Capacity of Medium Chromium-Nickel and Nickel-Chromium Alloys (Plotted on Fig. 7)

	Alloy	Load Capacity in lbs./in.² at 1000°F.	1100°F.	1200°F.	1300°F.	1350°F.	1600°F.	1800°F.	1900°F.	2000°F.	Remarks
1	16% Cr, 25% Ni, 0.11% C[a]	7000									1%—10,000 hrs.
2	18% Cr, 23% Ni, 0.24% C[b]	23000	(1120° / 15000)			2000					1%—10,000 hrs.
3	17% Cr, 24% Ni, 0.03% C[c] (No. 75)						1200				1%—10,000 hrs.
4	15% Cr, 25% Ni, 0.52% C[c] (No. MS)						1800				1%—10,000 hrs.
5	22% Cr, 22% Ni, 0.50% C[d]	25000	16000	9500	5000						1%—10,000 hrs.
6	25% Cr, 20% Ni, 0.12% C, V 0.18%[e]			7500							1%—10,000 hrs.
7	22% Cr, 23% Ni, 0.65% C[f]							1450	1160	870	Safe Load
8	22% Cr, 22% Ni, 0.50% C[d]	16250				2300					1%—100,000 hrs.
9	14% Cr, 27% Ni, 0.46% C[g] 3.6% W		(1110° / 24500)		(1290° / 13500)		(1470° / 4500)				1%—10,000 hrs.

[a]French, Kahlbaum & Peterson. Alloy 1010, Cast.[9]
[b]French, Cross & Peterson. Alloy A-347, Rolled.[10]
[c]Tucker & Sinclair. Alloys 75 and MS, Cast.[6]
[d]Strauss. Castings of Corrosion-Resisting Steels. Alloy 7, Table I, page 184, *Symposium on Steel Castings, A.S.T.M.-A.F.A.*, 1932, pages 175-199.
[e]Norton. Creep of Steels at High Temperatures. Alloy "C", Rolled.
[f]A.S.T.M. Committee B4, Appendix 1930,[11] B & W, Alloy 1100, Cast.
[g]Tapsell & Remfry.

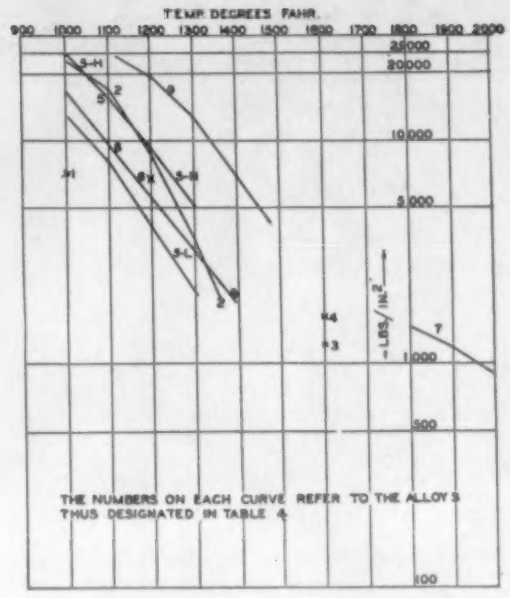


Fig. 7.

Table 5. Load Capacity of Nickel-Chromium Alloys ("35-15 Class") (Plotted on Fig. 8)

	Alloy	Load Capacity in lbs./in.² at 1000°F.	1100°F.	1200°F.	1300°F.	1400°F.	1500°F.	1600°F.	1700°F.	1800°F.	2000°F.	Remarks
1	11% Cr, 35% Ni, 0.28% C[a] 0.34% W (FS-2-B)	17000		8500	(1350° / 1500)							1%—1,000 hrs.
2	13% Cr, 35% Ni, 0.32% C[a] (FS-2-A)	22500		9000	1000							1%—1,000 hrs.
3	15% Cr, 35% Ni, 0.50% C[b]			3800	3300	2500	2000	1700	1500	1250	1250	Safe Load
4	15% Cr, 35% Ni[c]	5600	5000	4800	4400	3800	3000	2000	1400	450	100	Safe Load
5	17% Cr, 40% Ni, 0.40% C[d]									1000		Safe Load
6	16% Cr, 36% Ni, 0.60% C[e]					1800	1200	750	460	290	140	Design Strength, 1%—1,000 hrs.
7	19% Cr, 40% Ni, 0.95% C[f] (No. OS)							2500				1%—10,000 hrs.
8	27% Cr, 35% Ni, 0.11% C[a] (No. 1011)		15000		(1350° / 1500)							1%—10,000 hrs.
9	31% Cr, 33% Ni, 0.26% C[f] (No. 76)							2600				1%—10,000 hrs.
10	46% Cr, 50% Ni, 0.24% C[a,f] (No. 1008)		15000[a]					2400[f]				

[a]French, Kahlbaum and Peterson.[9] Alloys FS-2-A, FS-2-B (B, Annealed; A, As rolled), No. 1011, No. 1008 (Cast and Annealed).
[b]A.S.T.M. Committee B4, Appendix, 1930,[11] Calite "A".
[c]Manufacturer "A" Private Communication (As cast).
[d]A.S.T.M. Committee B4, Appendix, 1930,[11] Thermalloy "A".
[e]Michigan Steel Castings Co., Private Communication, "Misco Metal" (As cast).
[f]Tucker and Sinclair,[6] Alloys No. OS, No. 76, No. 1008 (Cast).

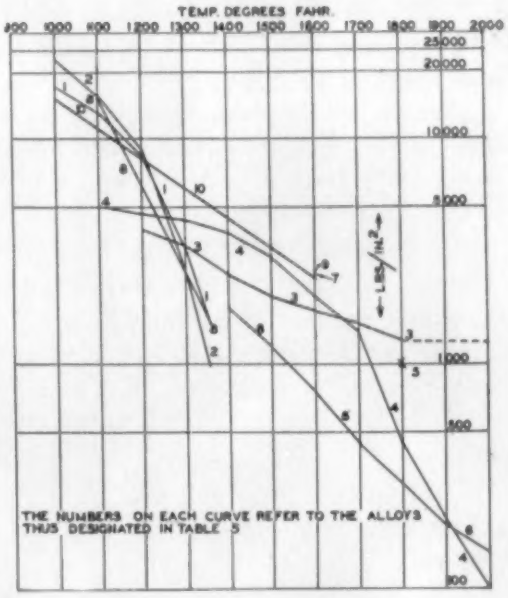


Fig. 8.

Table 6. Load Capacity of Nickel-Chromium Alloys (High Nickel) (Plotted on Fig. 9)

	Alloy	Load Capacity in lbs./in.² at 1000°F.	1100°F.	1200°F.	1300°F.	1400°F.	1500°F.	1600°F.	1700°F.	1800°F.	Remarks
1	14% Cr, 59% Ni, 0.87% C[a] (DH)							2400			1%—10,000 hrs.
2	15% Cr, 59% Ni, 0.41% C[a] (1009)	11000						1500			1%—10,000 hrs.
3	18% Cr, 51% Ni, 0.33% C[a] (77)							1500			1%—10,000 hrs.
4	19% Cr, 65% Ni, 0.80% C[b]									1000	Safe Load
5	18% Cr, 65% Ni[c]				4500	4000	3500	3000	2500	2000	1250	Safe Load
6	17% Cr, 75% Ni, 0.18% C[a] (CA)								2100			1%—10,000 hrs.
7	18% Cr, 73% Ni, 0.22% C[a] (78)								2000			1%—10,000 hrs.
8	21% Cr, 76% Ni, 0.15% C[a] (76-20)								400			1%—10,000 hrs.
9	18% Cr, 78% Ni, 0.51% C[d] (1007)	10000										1%—10,000 hrs.
10	15% Cr, 63% Ni, 7% Mo[e]								2250	1000	(1885° / 425) (2010° / 285)	"Creep Limit"

[a]Tucker and Sinclair,[6] Cast Alloys DH, No. 1009, No. 77, CA, No. 78. Rolled Alloy No. 76-20.
[b]A.S.T.M. Committee B4, Appendix, 1930,[11] Thermalloy "B".
[c]A.S.T.M. Committee B4, Appendix, 1930,[11] Calite "N".
[d]French, Cross and Peterson. Alloy No. 1007.[10]
[e]Rohn.[16]

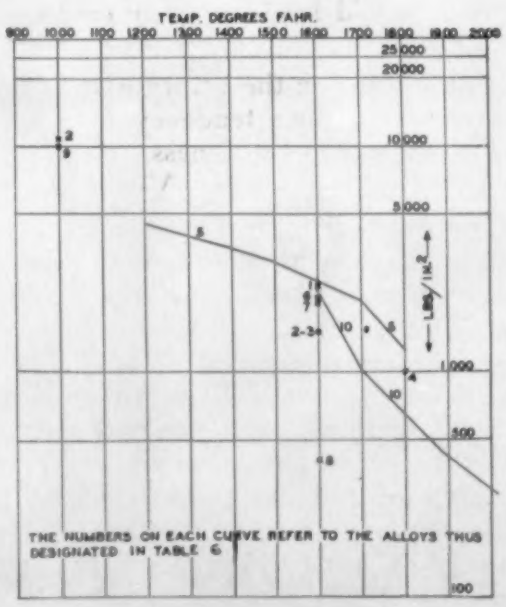


Fig. 9.

Table 7. Load Capacity of Chromium-Nickel Alloys (High Chromium, Low Nickel)
(Plotted on Fig. 10)

	Alloy	Load Capacity in lbs./in.^{2} at 900°F.	1000°F.	1100°F.	1200°F.	1300°F.	1400°F.	1500°F.	1600°F.	1700°F.	1800°F.	Remarks
1	19% Cr, 10% Ni, 0.04% C[a] (As rolled)				5000		4000	(1525° 1000)				1%—10,000 hrs.
2	19% Cr, 10% Ni, 0.04% C (Quenched 2100°)				8500		5000	1000				1%—10,000 hrs.
3	17% Cr, 9% Ni, 0.15% C[b] (E-1912)	(990° 10000)		(1165° 9000)		(1380° 5000)						1%—10,000 hrs.
4	20% Cr, 8% Ni, 0.29% C[b] 4.5% W (E-1114)		25000		12000		5000					1%—10,000 hrs.
5	Ni-Cr-W[c]	33500	23500	12500								1%—10,000 hrs.
6	20% Cr, 8% Ni, 1% Al[d]	14000	11000	9000	7000	5500	4500		3000	2500	2000	Safe Load
7	18-8 High Carbon[e]	(See Table "B" Figure 5 Composite Curve Nos. 2-3-5-6-7-8-9)										

[a]Kanter & Spring (From Pilling & Worthington[1]).
[b]French, Kahlbaum & Peterson.[9] Alloys E-1912 and E-114.
[c]Tapsell.[15] "Era" Alloy.
[d]A.S.T.M.-A.S.M.E. 1931 Symposium,[7] pages 97, 505. Calite "B".
[e]Transposed from Table 2 and Fig. 5. The composite curve for high C 18-8.

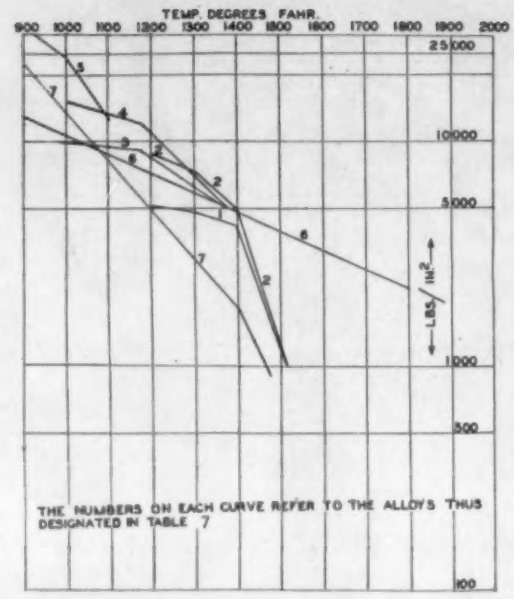


Fig. 10.

25% better load-carrying ability at 1300°F., than C steel. Curve 4 is for a 12% Cr steel as given by Tapsell[15] and shows scarcely appreciable improvement over C steel. Norton has given data for steels of 12.4% Cr, curve 5, 13.2% Cr, curve 6, 17.6% Cr, curve 7 and 27% Cr, curve 8, which indicate that, at least from 1200° to 1350° F., the 13.2% Cr and 17.6% Cr steels show marked increase in creep resistance, but the 27% Cr reverts to the same position as an extension of the curve for 5% Cr would take. Moneypenny[13] states, (page 443) that at 12 to 14% Cr, the plain Cr steels are distinctly stronger, especially at 750°-1100°F., than C steel, but raising the Cr to 17-20% lowers the strength.

Curves 5, 6 and 7, show the fallacy of the assumption, sometimes made too broadly, that the semi-log plot of log load vs. temperature is a straight line or a smooth curve of small curvature. If Norton's results are to be accepted, there is no telling what direction the plot will curve.

Of particular interest are the 1600°F. points from Tucker and Sinclair, and a stated "safe load" (not a creep value) for an industrial alloy, all on cast material, and all of higher Cr content. If the data are correct, the fact that Norton's wrought 27% Cr alloy was as weak at 1350°F. as Tucker and Sinclair's cast No. 73 alloy of 27.5% Cr, point 11, at 1600°F., it would appear that for such material the cast has by far the higher creep resistance. The other alloys at 1600° have both high Cr and high C. Obviously extrapolation from the data for wrought material to cast material and ignoring the C content would lead to highly erroneous design values in this case.

Limitations on the utility of the high Cr, plain Fe-Cr alloys are in their tendency to grain growth and their low-temperature brittleness. They shine in their ability to withstand S gases (see Moneypenny,[13] and MacQuigg, Symposium,[7] page 589).

The common 18-8 alloy has been studied more as a corrosion-resistant than a heat-resistant alloy, but because of its use in still-tubes, it has had some attention from the creep point of view. Table 2 and Fig. 5 give the data. Since the 18-8 still-tube tends to give way without warning, it is not planned to load it so as to allow it much deformation and creep values are available in terms of 1% per 100,000 hours. In Fig. 5, curve 1 is for the low C (below 0.08%) type, and the composite curve, 2, 3, 5, 6, 7, 8, 9, for higher C. Curve 10-11 is a combination of a tube-user's idea* of safe load and Rohn's[16] appraisal based on an unstandardized type of "relaxation" test which would not be included save that it appears to have the only figures on record above 1500°F. for this alloy.

With the exception of one point from Kanter and Spring, curve 4 (using their data for 1%-100,000 hours), all the data are quite concordant. Fig. 10 will bring in some other data.

If we compare Fig. 5 with Fig. 4 we see that the wrought 18-8 alloys at so low a creep rate as 1% in 100,000 hours have higher creep resistance than the highest shown by any of the plain Cr ferritic alloys at 1% in 10,000 hours. No data on cast 18-8 alloys are available.

Because of the low oxidation resistance, alloys under 15% Cr are seldom used. There are a few data on "reversed 18-8," i.e., 8% Cr, 20% Ni, from Norton, given in Table 3 and Fig. 6, also "safe load" values for an industrial alloy of this class. Norton's values are for a single lot only, but his 1% in 10,000 hours and 1% in 100,000 hours figures are consistent. If they may be accepted, the alloy shows a peculiar break in the curve, again indicating that extrapolation of supposedly straight line or smooth curves may be highly dangerous. The 1% in 100,000 hours curve is below that of Fig. 5 for 18-8 up to 1300°F., but coincides with it from there to 1500°F.

Reverting next to the alloys of normal Cr content, with the lower Ni content we note that Table 4 and Fig. 7 show, compared with Fig. 4 a much higher creep resistance, ascribable to the presence of Ni. Like Fig. 4, it shows very much higher creep resistance at high temperatures for the cast materials, than could be expected from extrapolation of the curves for wrought material. Even the very low C alloy, No. 75, curve 3 tested by Tucker and Sinclair is far above what would be expected from the curves for wrought materials. Their alloy No. MS, curve 4 shows the effect of C content. The curve for Tapsell and Remfry's high C, high Si alloy, 9, with 3.6% W has the same general shape as the other curves and would extrapolate to the same level as the high C, high Si alloy without W, tested by Tucker and Sinclair (Alloy MS, curve 4).

[15]H. J. Tapsell. Creep of Metals. Oxford University Press, New York, 1931, page 228.

*Symposium on Effect of Temperature on Properties of Metals, American Society for Testing Materials-American Society of Mechanical Engineers, 1931, page 76.

[16]W. Rohn. Das Verhalten metallischer Werkstoffe bei Temperaturen bei denen auch nach kleiner Verformung Rekristallisation eintritt. *International Association for Testing Materials*, Zurich, Vol. I, 1931, pages 177-182, Fig. 4.

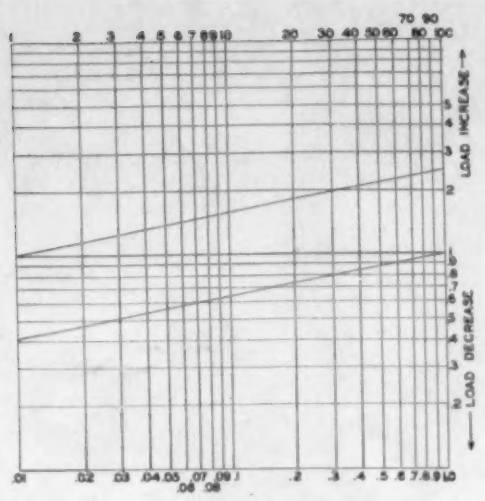


Fig. 11. Creep Factor Due to Change in Load. Based on Creep = K (Stress)^5 (F. H. Norton)

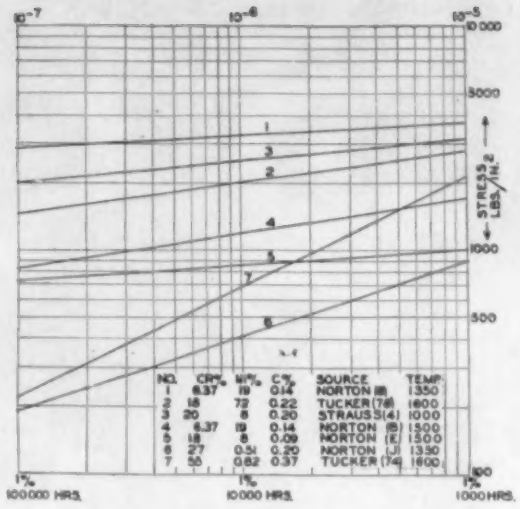


Fig. 12. Rate of Creep inch/inch/hour

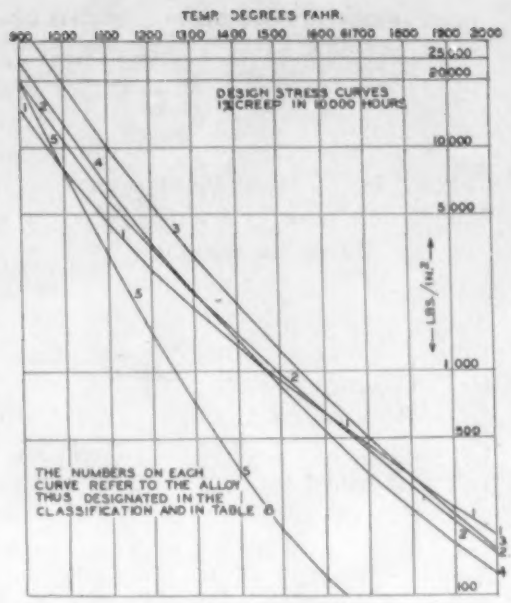

TEMP. DEGREES FAHR.
DESIGN STRESS CURVES
1% CREEP IN 10000 HOURS
LBS./IN.2
THE NUMBERS ON EACH CURVE REFER TO THE ALLOY THUS DESIGNATED IN THE CLASSIFICATION AND IN TABLE 6

Fig. 13.

Table 5 and Fig. 8 deal chiefly with the common industrial alloy 15% Cr, 35% Ni. Available data for actual creep tests for the same alloy over a range of temperatures are given only at a very high rate of deformation, from the work of French and coworkers[9] and of Tucker and Sinclair.[6] Manufacturers' estimates of "safe loads" for the alloys of this group are vastly different. Curves 8 for creep tests and 6 from a manufacturer's estimate appear to be almost continuous, as does curve 10 which when extended, follows for a considerable range the course of curve 4 for the higher strengths. One manufacturer's estimate, curve 4, follows the upper curve 10 to 1500°F., and then drops to the lower curves (8 and 6). The data for 1% in 1000 hours on alloy FS, curve 1 follows the upper curve (10), to 1200°F., and then drops to the lower course, curves 8 and 6. Another manufacturer's estimate, curve 3, starts near the lower curve and ends near the upper one. (It is not clear why the estimate of curve 3 should allow as high a safe load at 2000° as at 1800°F.)

The data of Tucker and Sinclair for the high C or high Cr alloys tend to corroborate the upper curve. One might conclude that this class of alloys is highly sensitive to changes in C and Cr content. The indications are that the cast material is superior to the wrought at high temperatures. Such wide variations indicate the need for study, by actual creep tests, of the variables concerned, when alloys of the same nominal composition are said by one to have at 2000°F., a load-carrying ability of 150 lbs./in.^{2}, and by another, 1250 lbs./in.^{2}

In the high Ni group of alloys, Table 6, Fig. 9, creep data over a range of temperatures are lacking. The isolated figure for wrought No. 76-20, curve (point) 8, by Tucker and Sinclair, brings out clearly the better strength of cast material. Rohn's data are hardly comparable, both because they were obtained by a non-standard method, and because of the presence of considerable Mo, but are included because they again give data at higher temperatures than those from other sources.

Tucker and Sinclair's figures in Fig. 9 (curve or point 1, 2, 3, 6, 7, 8, 9), at 1600°F. are not quite so high as those in Fig. 8 (points 7 and 9), the higher Ni apparently not having helped.

Reverting to the 18-8 type, Table 7, Fig. 10, the curve for the higher C (over 0.07%) alloys at 1%-100,000 hrs., of Fig. 5 (curve 2, 3-9), has been drawn in as curve 7. Curves 1 and 2 from Kanter and Spring[17] indicate that quenched material has somewhat better creep resistance than as-rolled material. A manufacturer's "Safe Load," curve 6 is shown for a cast alloy of the general 18-8 type with high C (up to 1.20% C), and with Al (1-8%). This has a very different slope from that for ordinary 18-8. Curve 3 from French for a wrought alloy approximates curve 6, while curve 4 for a wrought alloy with 4.5% W, and curve 5 from Tapsell, for an alloy of unknown composition, but supposed to contain Ni, Cr and high W, blend into curve 6 at 1400°F. Kanter and Spring's data more or less follow the upper curve to 1400°F. and then drop to the usual curve for 18-8. This tendency to change slope is noted in several of the previous curves and figures.

Until the work of Tucker and Sinclair, there were very few creep data at temperatures as high as 1600°F., and even that is not high compared to the service re-

[17] J. J. Kanter & W. Spring. Some Long Time Tension Tests of Steels at Elevated Temperatures. *Proceedings American Society for Testing Materials*, Vol. 30, Part I, 1930, page 110. See also *Symposium on Effect of Temperature on Properties of Metals, American Society for Testing Materials-American Society of Mechanical Engineers*, 1931, page 517.

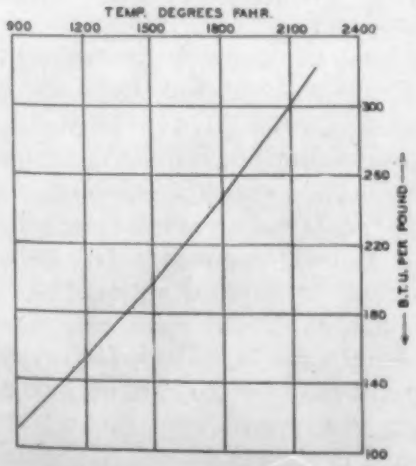


Fig. 14. Heat Content Curve for Heat-Resistant Alloys (approx.)

Table 8. Physical Constants for General Design Purposes

	1	2	3	4	5
Carbon	0.30- .50%	0.30- .50%	0.30- .50%	0.20- .35%	0.20- .40%
Nickel	55.0 -65.0 %	35.0 -45.0 %	18.0 -25.0 %	8.0 -15.0 %	0.00- 6.0 %
Chromium	15.0 -20.0 %	15.0 -20.0 %	25.0 -30.0 %	25.0 -30.0 %	24.0 -28.0 %
			Linear Coefficient of Expansion (1000°-2100°F.)		
Per °C.	16 x 10-6	20 x 10-6	19 x 10-6	17 x 10-6	13 x 10-6
Per °F.	9.8 x 10-6	11 x 10-6	10.6 x 10-6	9.4 x 10-6	7.2 x 10-6
			Weight Table (Approx.)		
lbs./ft.^{3}	505	495	478	474	475
lbs./in.^{3}	0.294	0.288	0.278	0.276	0.277
			Thermal Conductivity (Approx.)		
Steel (0.20% C) 100%	33%	35%	35%	40%	75%

quirements of furnace alloys. We must conclude that we know all too little about actual creep of heat-resistant alloys at really high temperatures. Design on such a basis is certainly difficult.

If we wish to apply a factor of safety or if we are forced to extrapolate from a high rate of creep to a lower one and experimental data are lacking, the best we can do is to assume that the alloy we are dealing with acts like the majority of the Cr-Ni-Fe alloys and, at any one temperature, will increase its creep rate at higher loads and decrease it at lower loads according to the same exponential function.

Norton found that his data could be reasonably well expressed by straight line plots of log stress against log rate of creep for a given temperature, the slope corresponding on the average to the equation—Creep rate = $(\text{stress})^5$. Kanter,[18] however, shows log-log plots for a 0.33% C steel that are parallel for temperatures of 750°-1000°F., but at 1200°F., the plot has a new exponent (is not parallel to the rest of the family of curves), and is no longer straight but tends toward a much greater rate of creep at low stresses than would be expected from high stress tests on the basis of the slope for lower temperatures.

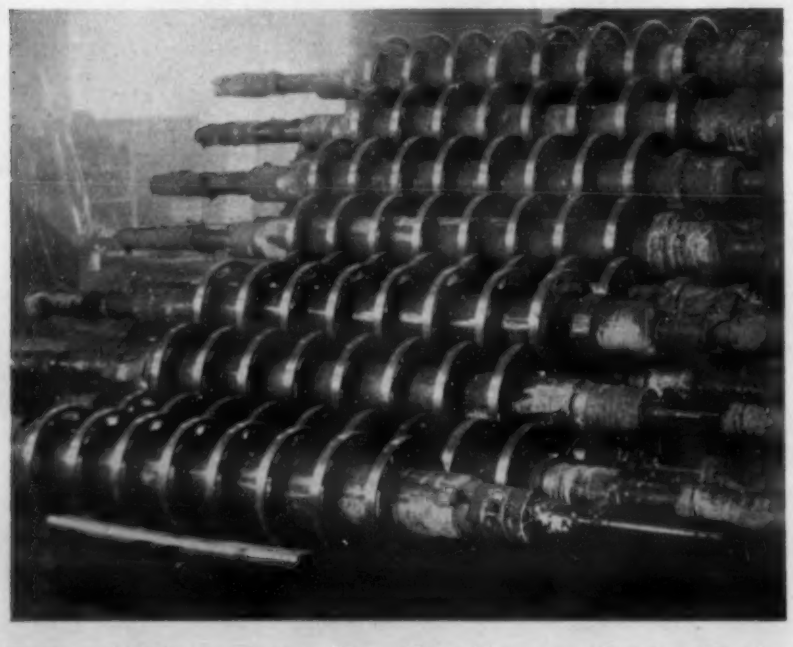
Norton states that the 5th power is average, but powers have been observed as high as the 17th and as low as the 3rd. For general conditions in dealing with the heat-resisting alloys of the austenitic class, the 5th power rule seems to work well in practice and for that reason has been used by the author, for the calculation of load values for various rates of creep for a given alloy at a given temperature when he has no more accurate guide.

On that assumption, doubling the load producing a given creep rate at a given temperature will produce a creep rate of 32 times the original rate ($[2]^5 = 32$). Similarly, dividing the load by 2 under the same circumstances will result in dividing the creep rate by 32.

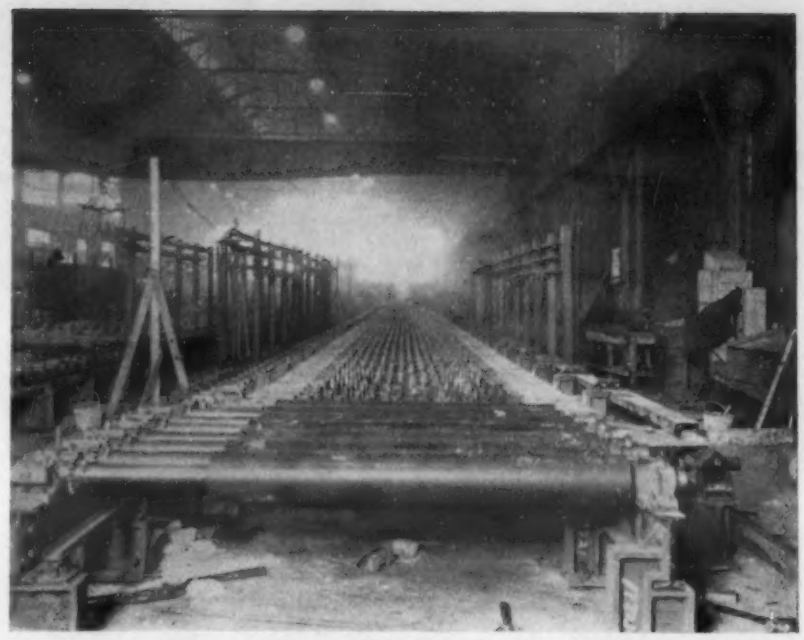
Fig. 11 is a curve based on this assumption, by which changes in load can be interpreted in terms of change of creep rate, all other factors being constant. It is a function of the 5th power in terms of the relation of the percentage of change in unit stress to the factor of change in creep rate resulting from the change in load.

As an illustration, it is desired to determine the effect

[18] J. J. Kanter. Discussion, *Symposium on Effect of Temperature on Properties of Metals, American Society for Testing Materials-American Society of Mechanical Engineers*, 1931, page 238, Fig. 1.



Shafts and Disks or Kathner Normalizing Furnaces. (Courtesy Duraloy Company.)



Installation of Shafts and Disks in Kathner Normalizing Furnaces. (Courtesy Duraloy Company.)

on the creep rate 1%-10,000 hrs., of an increase in load or unit stress, of 20%. Locating on the curve the point 1.2 as an ordinate, the abscissa is the factor by which the original rate is to be multiplied in order to be proportional to the 5th power of the change in load. In this case, the abscissa is approximately 2.4 so that with a 20% increase over the load normally producing 1%-10,000 hrs., creep, the new creep becomes (2.4 x 1) or 2.4%-10,000 hrs. Or, looking at the effect in a different way, a 20% increase in load over the original load producing 1%-10,000 hrs., would result in the total 1% creep being attained in (10,000/2.4) or 4166 hrs.

That this 5th power rule has exceptions is shown in Fig. 12. Curves 2, 3, and 4 show approximate agreement with the rule, but curves 1, 5, 6, and 7 show great deviations from it.

The effect of increase of temperature at a given load appears to approximate an exponential function. But instead of creep increasing in proportion to the 5th power of the temperature, the exponent itself seems to increase with the temperature. If actual data for this relationship are plotted on semi-log paper as in Figs. 4 to 10, the curves starting at around 1000°F., tend to be either straight or convex upward when they show a regular trend. From 1000° to 1400°F., in the alloys herein considered, there are possibilities of strain hardening; in the metastable ferritic steels there is a transition to austenite, and at the high end of this range in most of the alloys considered, precipitated carbides begin to be taken into solution again. Hence, direct straight line extrapolation above 1400°F., from the 1000°-1400°F. range appears unwarranted.

In the writer's opinion, based on observations of commercial behavior (and supported to a certain extent by the recent work of Tucker and Sinclair), while the straight line and convex upward tendencies may be apparent in the range 1000°-1400°F., due to the influences just mentioned, the actual trend of the curve over the range 1000°-2000°F., is concave upward, not convex. If the convex upward trend persisted over the entire range, it would be almost impossible to design continuous furnace equipment for operation at 1800°-2000°F., yet there are many walking-beam and dry-shaft roller type sheet normalizers in successful every-day operation. The temperatures in the hot zones of these furnaces range from 1750° to 2000°F. and the alloy parts in such zones are designed on a basis which would not be justified by the convex upward trend.

Fahrite heat resisting valves for open hearth and soaking pit furnaces. (Courtesy Ohio Steel Foundry Company.)

For the writer's own design purposes, he has arbitrarily assumed that the Fe-Cr-Ni alloys of commercial importance for furnace parts can be lumped into 5 classes as follows:

	1	2	3	4	5
C	0.30- 0.50%	0.30- 0.50%	0.30- 0.50%	0.20- 0.35%	0.20- 0.40%
Ni	55.0 -65.0%	35.0 -45.0%	18.0 -25.0%	8.0 -15.0%	0.00- 6.0%
Cr	15.0 -20.0%	15.0 -20.0%	25.0 -30.0%	25.0 -30.0%	24.0 -28.0%

The first 4 classes are austenitic, the fifth a ferritic group. For each of these classes, there has been drawn in Fig. 13, the expected creep curve for good quality material representing permissible deformation on the basis of 1%-10,000 hrs. The designers, who think of creep at all, seem, for furnace parts, to be thinking in terms of determining loads for 1% creep in 10,000 hrs. and then allowing a factor of safety. The writer's design creep curves are meant to correspond to the expected creep without a factor of safety.

The curves as shown should not be extended much beyond 2150°F., as the possible formation of delta iron beyond that point will result in much lower load capacities ascribable to the ferritic series such as class 5, and very different from what an extension of the curve would indicate.

The curves are frankly extrapolations from scanty information and guesses as to the facts. Furnace parts so designed have, however, given such service as to indicate that the curves are a happy medium between too optimistic and too pessimistic designing. The curves refer to plain Ni-Cr-Fe alloys of the compositions given, and of the C contents shown, in all cases below 0.50% C. It should be noted that the presence of higher C, or of additional elements such as W, Mo and Al may be expected to improve the load-carrying ability, but data are lacking for complete design curves for such alloys. While in alloys of higher Ni or Cr than those herein considered, there is some evidence that increase in C weakens instead of strengthens, that is probably not true for the 5 classes dealt with in this discussion.

It should be noted in comparing these curves with Figs. 4 to 10 inc., that the C and Cr contents of the classified alloys are higher than those of many of the laboratory alloys on which creep rates have been determined, and consequently should have consistently higher load capacities.

Linear coefficients of expansion, weight tables for estimating purposes, and approximate conductivity values are contained in Table 8 for each of the classified alloys. Fig. 14 gives data for thermal capacity over the useful range of temperatures which is applicable to all of the classes in the absence of any more accurate data.

It will be noted that no differentiation has been made in the design curves, as to whether a given alloy was in the cast or wrought condition. There is a fairly widespread belief, supported by considerable evidence, that for high temperature service, above the strain hardening range, alloys of large grain size such as is met with in castings, are superior to those of the same composition but of smaller grain size as in the wrought state. On account of the greater likelihood of minute flaws and blowholes in castings, even those that are given X-Ray inspection to throw out castings with gross imperfections, the writer has balanced one factor against another and uses the same design values for both cast and wrought material. In his judgment this is the best thing to do in the present state of ignorance.

When a furnace designer or furnace user is offered heat-resisting alloys under fancy brand names, marketed under the high power salesmanship common in this highly competitive industry, he is truly perplexed to know whether the claims made are justified or "hokum." It would be a great relief if the alloys were sold on the basis of actual, reliable and comprehensive creep tests made at as high temperatures as the furnace designer or furnace user wishes to use, together with ample evidence that the specimens tested were representative of regular production, and that the properties will be duplicated in all shipments.

The alloy maker would be rid of many of his own perplexities if he had quantitative proof, by reliable creep tests, of the effect of changes in Ni, Cr and C contents, and of those of the addition elements such as W, Mo, Al, Si, Ti, etc.

The testing engineer would be freed from many of his own troubles if he could be sure how far he can safely extrapolate his results, whether any definite exponential or power function laws really hold for this class of materials at these temperatures, and whether data for wrought alloys can be correctly applied to cast alloys.

Few such important engineering subjects have such small islands of known facts so sparsely scattered amid the sea of speculation and conjecture. The whole subject seems one ripe for joint action by the makers and users of heat-resistant alloys, looking toward the accumulation of definite engineering knowledge to replace the vague generalizations and rough guesses on which designers so far have had to rely.

The discussion above has been based primarily on load-carrying ability. Many other factors enter into the choice of an alloy for a given service, and some of these will be considered in a subsequent article.

Checker brick supporting plates used in blast furnace stoves designed by Arthur G. McKee Company. (Courtesy Michigan Steel Casting Company.)

EDITORIAL COMMENT

(Continued from page A 13

No inkling is given in this article whether there is any hope of one change in the set-up of Mines that would result in real economy. In one of its moments of aberration, Congress spread the Bureau of Mines all over the map, with little stations and minor offices located at a considerable number of state universities, ostensibly to better serve in the solution of local problems, and restricted the percentage of its funds that the Bureau could spend in Washington. Hence, centralization at Washington or elsewhere of its research activities with resulting greater efficiency in supervision and prevention of duplication of equipment (or the necessity of getting along with inadequate equipment) has never been possible. Abolition of most of the one-horse branches and concentration into two or three real laboratories like that at Pittsburgh, would help a lot but cannot be carried out unless the politicians will go lie down and let the Bureau do what it has long known it ought to do.

Turning now to the situation at the Bureau of Standards, it has been necessary, Bureau representatives tell us, to close out entirely and abruptly, "like switching out a light," the work on development of methods of metallographic technique, on X-ray study of crystal structure, on thermal conductivity of metals and on the mechanism of the quenching of steel. Particularly in the first and last topics, the Bureau has done much pioneer work and it is a pity that its experience and equipment can no longer be utilized on them.

Some projects already brought close to a reportable conclusion, on high-strength cast iron, equilibrium of liquid iron with the oxides of carbon, spark testing and the Preece test, are to be dropped with a minimum of further work.

Two projects supported by funds transferred from other Government departments, corrosion of the duralumin type of alloys and its prevention, and metallurgical problems relating to printing plates, will continue. Bureau projects on methods of evaluating the wear-resistance of metals, on the creep of single crystals of metals at high temperatures, and on transverse fissures in rails will also go on at a reduced rate.

Metallurgical lines of activity, outside the metallurgical division itself, that are severely cut, comprise those on soil corrosion, electroplating, dental alloys, etc. The soil corrosion work is an example of a controversial field in which studies stretching over a long period of years, and by an entirely unbiased agency, are essential to findings that will be accepted by all interests, so it would be a calamity to have the work cut off entirely.

The Bureau's work on electroplating has done much to pry the industry out of its rule-of-thumb attitude, being as valuable educationally as it is technically. We are sorry to see that diminish.

Very few projects will go on at the former rate of attack. Those which are not to be greatly curtailed are on the preparation and properties of pure iron, on spring materials, international coöperative work on methods for determining gases in metals, and the study of the causes for failure of the defective bridge wire from the Mt. Hope and Ambassador bridges. The last is a problem that could not be as well attacked by any other group and it certainly deserves the premier position of importance the Bureau is giving it.

The diminished funds available to the Bureau for metallurgical work cannot be wholly applied to research. Other angles of work come first and only the residue is left for research. The Bureau will apparently be called upon to do an increasing amount of the inspection type of testing on Government purchases, and minor researches for other Government departments, with very inadequate funds to cover the cost. Such testing as is done for the public—and only that which cannot be done by other laboratories or that which is in the nature of umpire tests will be done—is to be paid for, according to recent action of Congress, at a rate commensurate with its cost, including overhead. Similar conditions apply in the case of research work that is carried out for industry on the "Research Associate" plan.

In past years, projects suggested by industry and considered by the Bureau to be of the type it might properly deal with on its own funds, were sufficient funds available, were often taken up when industry showed its own interest by paying the salary of the Research Associate. The cost of supervision and overhead, supplied by the Bureau from public funds, usually amounted to at least as much as was put in by industry. Hereafter, those supporting the project must cover other expenses beside the Associate's salary. As usual, Research Associate projects must be those of interest to and supported by a representative group of the industry concerned, not merely those affecting an individual firm or of merely local interest.

The practical difficulty in all this testing work is that while what it costs the Bureau to do it is paid by those asking for the work, it is paid to the Treasury and not to the Bureau, and there are no signs that Congress has any intention of reappropriating to the Bureau what it thus earns.

Hence, the more accommodating the Bureau is, in doing testing and supervising Research Associate activities, the more its regularly appropriated funds are cut into and the less research it can do on the problems it has itself selected.

Another service that cuts into time and funds, to an amount seldom appreciated, is the answering of requests for information made by letter or personal visit. This service, of course, cannot be curtailed even though some of the facilities for doing it quickly and economically have been lost by the forced "economy."

Coöperation with technical committees of national societies will be curtailed in that long investigative programs, which such committees are prone to lay in the Bureau's lap, obviously cannot be taken on. A reasonable amount of contact with such committees is expected to be maintained.

On the whole, the metallurgical work of the Bureau has been greatly "deflated." A considerable number of important, fundamental, and constructive lines of effort have had to be dropped, but good judgment is, in general, being exercised in the selection of projects retained. Many man-years of valuable experience are being lost by the cutting of the metallurgical staff to not much over half its former number, yet most of their accumulated experience is still available in the persons of the men retained who have coöperated in the work of those released.

If too much time does not elapse before more generous appropriations are again available, the recessed work could be resumed without great difficulty and the hiatus may serve to show more clearly which of the projects deserve resumption. Indeed, the clearing of the decks may make it more feasible later, since fewer old projects requiring completion will be under way, to attack new problems that will then be of more importance than they may now seem to be.

We hope that the metallurgical research of the Bureau may proceed without too great permanent handicap, and that the stage may continue to be set for other achievements as epochal as that made by Merica when he laid the foundations for an understanding of precipitation-hardening phenomena. The advances directly traceable to Merica's work have been worth far more than all the Bureau's metallurgical research has cost.—H. W. Gillett

The Metallurgical Work of the U. S. Bureau of Mines*

by R. S. Dean**

IN SELECTING problems for study the Bureau is guided by the value of the solution to the conservation of our natural resources and the importance of the problem to our national economy, particularly the limitation of foreign monopolies of either processes or raw materials. By no means all of the problems suggested can be undertaken, and problems for coöperative effort are selected on the basis of the willingness of the coöperating individual or company to publish the results of the study and on their ability to contribute substantially to the solution of the general problem in hand.

In view of the necessity for economy in all Government agencies, the volume of metallurgical work done by the Bureau of Mines necessarily must be decreased. The following outline will indicate the investigations that it will be possible to continue, although not in every case with the intensity we would prefer.

METALLURGICAL research and investigation have been an important part of the work of the Bureau of Mines since the first few years of its organization. From individual investigations designed to help the miner in a direct way, much of the metallurgical work of the Bureau has progressed to the broader phase of fundamental research and development.

Direct Service Work of the Bureau

While the Bureau cannot undertake to make assays or tests of ores from individual properties, it does examine a very large number of samples sent from the newer parts of the country by prospectors, and gives general advice concerning the value of these ores and possible treatment methods. By far the largest number of samples received are gold ores.

A very great number of requests for metallurgical information are also received and are answered where possible by reference to the Bureau's publications.

Strategic Mineral Investigations

In spite of the fact that this country has the largest metallurgical industry in the world, there are several important metals which are not produced in this country in sufficient amount to supply domestic needs. Among these may be mentioned manganese, chromium and tungsten. The Bureau is investigating methods of utilizing the domestic sources of these minerals.

Manganese. A comprehensive survey of the available manganese ores, their beneficiation and smelting as well as the methods of using alloys produced from them, has just been completed and the results summarized in a bulletin which is now ready for printing.

Chromium. Methods for the concentration, by flotation and magnetically, of low-grade chromite deposits which occur in California and elsewhere, have been developed and are being intensively studied. In this connection development of the theory and practice of a.c. magnetic separation has made possible the separation of practically pure chromite. The Bureau will welcome the opportunity to study the concentration of any large chromite deposits in this country.

Tungsten. Two types of tungsten ores occur in this country, scheelite or calcium tungstate, and ferberite or iron tungstate. The Bureau is studying both types of ores and has found methods of concentrating both by flotation.

In coöperation with the Wolf Tongue Mining Company, one of the largest potential producers of ferberite, the Bureau is also investigating the direct reduction of ferberite to ferrotungsten. This has been accomplished on a laboratory scale. It is hoped that this direct reduction coupled with concentration will enable the domestic material to compete with that imported from China.

IRON AND STEEL INVESTIGATIONS

Beneficiation of Iron Ores

A survey of iron ores has been made with respect to their

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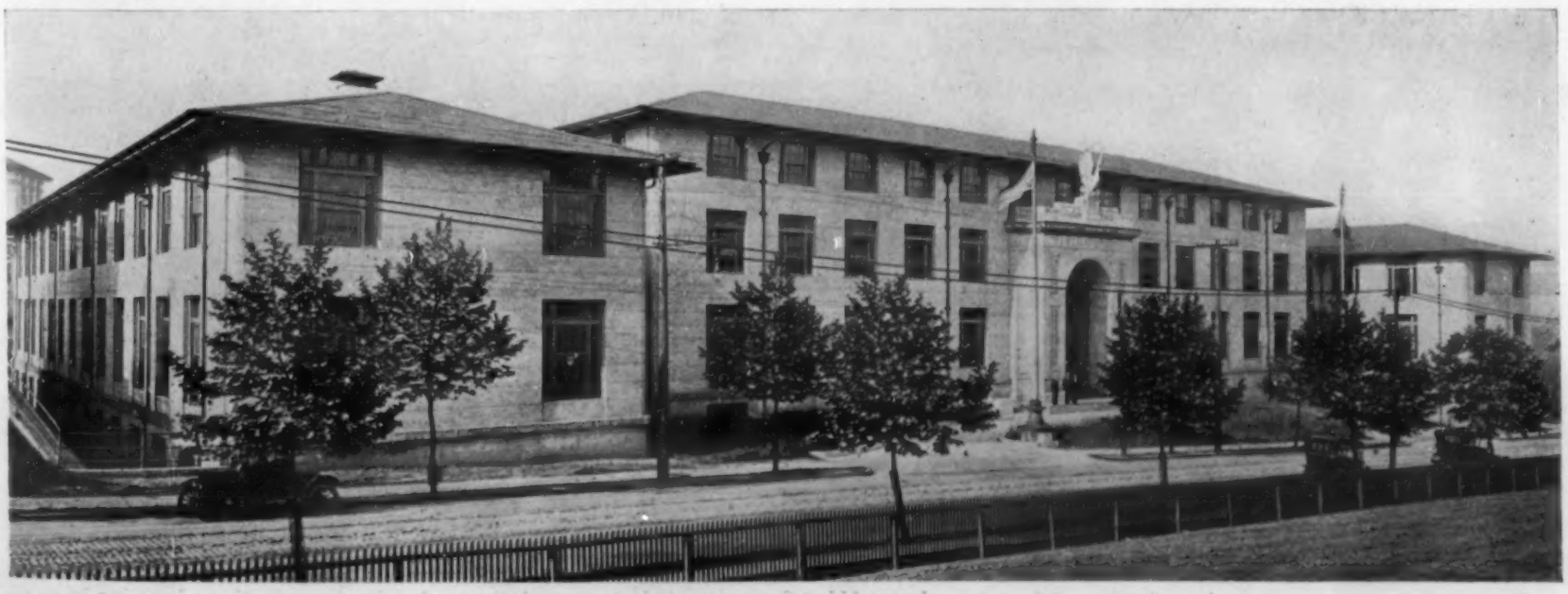
**Chief Engineer, Metallurgical Division, United States Bureau of Mines.



Pittsburgh Experiment Station of the U. S. Bureau of Mines at Pittsburgh, Pa.

amenability to rigorous concentration, and methods of concentration are being studied. These studies include microscopic studies, methods of crushing and grinding, and magnetic and flotation studies.

Natural Gas Reduction of Iron Ore

Experiments now being brought to conclusion show that by the use of an appropriate catalyst for the pre-combustion of natural gas, iron ore may be reduced to sponge iron substantially without further added heat. This process should be especially valuable where natural gas is cheap and coke is not available.

Direct Production of Iron and Steel from Purified Ores

The direct utilization of many ores capable of a high degree of concentration, particularly Eastern magnetites, is an important problem. In coöperation with the Reading Iron Company, the Bureau has developed methods for the direct production of iron and steel from such concentrates. Further studies of these methods are under way.

Use of Sponge Iron in Production of Quality Steel

In coöperation with the Henry Disston Sons Company, the Bureau is studying the use of sponge iron in the manufacture of certain tool steels. These studies include a careful comparison of the impurities and how they are combined in the steel. For this latter purpose a combination of heat treatment and magnetic tests is proving most useful.

Agglomeration of Iron Ores for Blast Furnace Use

The existence of non-uniformities in gas distribution, temperature and smelting work in the blast furnace can be traced to irregularities in the size of the feed. The usual methods of agglomeration such as sintering and briquetting are being studied, as is also the use of glomerules, which has been developed in the Bureau. In this latter method the charge of fine ore is moistened and caused to ball up, so that the individual glomerules are ¼ to ¾ inch in diameter. By heating to a temperature above 1000° C. these glomerules obtain considerable mechanical strength and yet remain easily reducible.

COPPER METALLURGY

Flash Roasting of Copper Ores

The best outlook for improvement in the economics of copper smelting is some method of saving the sulphur and iron contents of copper ores. The flotation process used for concentration yields a fine concentrate. Methods of burning this concentrate to give gases high in sulphur and a product from which the copper and iron can be separated are being studied.

In connection with this work a complete study of copper ferrites has been necessary. An interesting discovery has been that of the existence of two forms of copper ferrites, as revealed by their X-ray spectrograms.

Leaching Studies

The biggest stumbling block in the way of general use of leaching as a method of recovery of copper from its ores has been the insolubility of the chalcopyrite and of the copper ferrite. Methods for disintegration of these resistant structures are being studied and some promising results have been obtained.

ZINC METALLURGY

Methane Reduction of Zinc Ores

Comprehensive thermodynamic studies of zinc-smelting reactions, published in Bureau of Mines Bulletin 324, have led to development of the methane process for the reduction of zinc ores. In this process the zinc oxide is reduced by the reaction $ZnO + CH_4$ and gave $CO + Zn + 2H_2$. The usual side reactions which take place with the formation of CO_2 and water are inhibited by the use of an excess of methane and an appropriate catalyst. The laboratory phase of this work is nearly completed and it is expected that its commercial use will be attempted in the near future.

Removal of Cadmium from Zinc Concentrates

The preferential reduction of cadmium at controlled temperatures and ratios of carbon monoxide and dioxide, has been shown to be possible and the conditions necessary for the removal of the cadmium from zinc ores worked out. The results of this work are now in course of publication.

LEAD METALLURGY

Blast Furnace Studies

For several years the Bureau has studied smelting in the lead blast furnace, in coöperation with a number of Western lead smelters. The results of this work have already appeared in a number of publications and further papers are now in preparation. This plant investigation is supplemented with laboratory studies, and the work of the Bureau on lead metallurgy is being summarized in a comprehensive bulletin on this subject.

PRECIOUS METAL METALLURGY

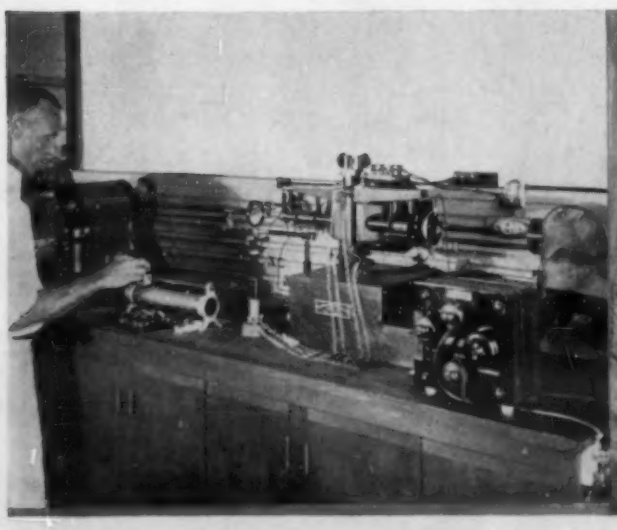
Refractory Gold Ores

Many gold ores are not susceptible to direct cyanidation and must be roasted. In this process the gold frequently is contaminated so that good recoveries are not obtained. Studies of methods for the treatment of these ores have already solved a number of difficult treatment problems and in view of the current importance of gold metallurgy this work is being actively pursued.

Gold Flotation

Flotation as a method of treatment for gold ores has been given special study by the Bureau, and methods of producing richer concentrates have been developed.

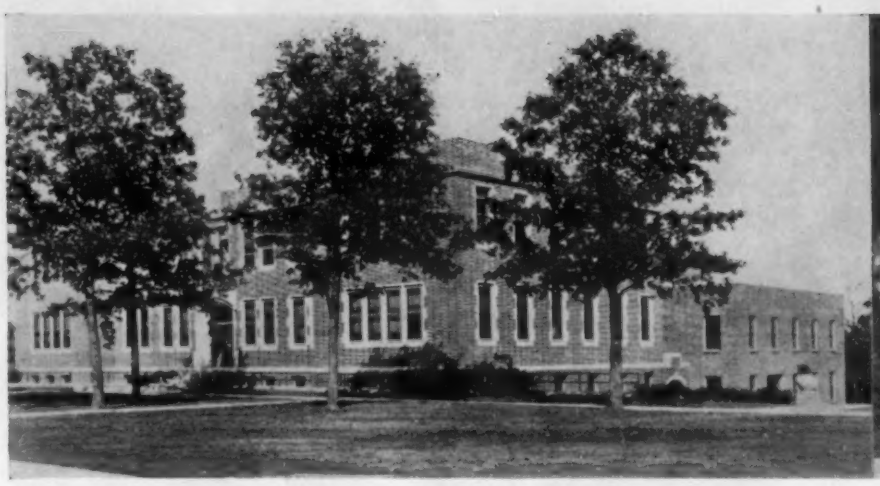
It has also been found that over-grinding, which causes the gold particles to become coated with slime, is a frequent source of gold loss in flotation.



Einthoven string galvanometer for investigation of the behavior of minerals in an alternating magnetic field.

Experimental blast furnace to study the smelting of iron ores and manganese ores.

Calorimeter for the determination of specific heats of metallurgically important materials.



Mississippi Valley Experiment Station of the U. S. Bureau of Mines, at Rolla, Missouri.

Pacific Experiment Station of the U. S. Bureau of Mines at Berkeley, California.

Recovery of Gold in Copper Concentrators

In the present method for copper concentration the Bureau has found that frequently gold is depressed along with the pyrite and lost. Methods to prevent the loss of this gold have been developed.

ORE DRESSING

Non-Sulphide Flotation

The Bureau has pioneered in the development of flotation of the non-sulphide minerals. Methods are now available for the flotation of practically all of the important non-sulphide minerals and a great deal has been accomplished in the separation of these minerals. At the present time the work along this line includes particularly the tungsten and chromium minerals, as well as cyanite and other non-metallics.

Crushing and Grinding

The importance of methods for crushing and grinding in order to free the valuable minerals from the worthless gangue can hardly be overstated. The relation of power to surface produced and the efficiency of various types of ball mills are receiving careful study. Radically new methods of ore preparation are also being developed. Principal among these should be mentioned explosive shattering, in which the ore is subjected to an explosion of superheated steam.

Magnetic Separation

Magnetic separation has long been recognized as an important method for the concentration of iron ores. Its application to other iron-bearing minerals has not, however, been generally developed. Studies of this method of concentration are being made, with particular emphasis on the special heat treatments which permit the separation of minerals in the alternating magnetic field.

FUNDAMENTAL STUDIES

Thermodynamic Studies

Studies of the thermodynamics of metallurgical reactions have been under way in the Bureau for several years. Among the bulletins already published covering this work may be mentioned the following:

Bulletin 296 Iron Oxide Reduction Equilibria, a Critique from the Standpoint of the Phase Rule and Thermodynamics, by O. C. Ralston, 1929, 326 pages.

Bulletin 324 Zinc Smelting from a Chemical and Thermodynamic Viewpoint, by C. G. Maier, 1931, 93 pages.

Bulletin 350 Contributions to the Data on Theoretical Metallurgy. I. The Entropies of Inorganic Substances, by K. K. Kelley, 63 pages.

A bulletin on high temperature specific heats of the metallurgically important subjects is now in the course of publication, and further studies of this nature are under way. These studies have permitted the development of such processes as the natural-gas reduction of zinc and iron ore, and the separation of cadmium from zinc ores, which have previously been mentioned.

Mineral Physics Studies

More recently the Bureau has turned its attention to obtaining fundamental metallurgical information of a different class, namely, the physics and chemistry of minerals, which constitute the raw materials of the metallurgical industry. At present this work is confined largely to the study of electric and magnetic properties.

As stated at the outset, in the selection of this program the Division has been guided by two major objectives, first, the development of methods which will permit the most advantageous use of our natural resources, and second, the control, so far as possible, of the best metallurgical methods by our own nationals. For this latter purpose research over a wide field is necessary to limit the foreign monopoly of new metallurgical developments which is granted under the patent system. While the Bureau cannot hope to make any considerable number of the major metallurgical inventions which will be forthcoming within the next decade, nevertheless by assiduous cultivation of newly developed fields it can hope to lessen the chances of non-nationals obtaining such monopolies as were held, for example, under the flotation patents, which cost American industry, in royalties to foreign interests, many times the expense of all the Bureau research to date.

The Bureau is of course always interested in new metallurgical developments and welcomes the opportunity to be of help in developing important mineral resources.

In its coöperation with individual industries we feel that since the results when complete are available to all, we are working in the interest of the public rather than of an individual. We are glad to coöperate with any individual or group in the study of metallurgical processes, where the results can be made public, but in view of our very limited personnel we must for the present restrict ourselves to the general subjects already under investigation. Congress has indicated that coöperating groups will be expected to carry the expense of coöperative work.

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The Cooley Electric Furnace Company recently has been organized to manufacture Bluehead Electric Furnaces, for use in the laboratory and tool room. W. B. Cooley, who has been closely associated with the electric furnace business for many years, is in charge. An exclusive license for the use in electric furnaces of the Doreco heating element has been granted by the Doherty Research Corporation. General offices and factory are located at 47-32 Van Dam Street, Long Island City, N. Y.

As of August 1, 1933, **Combustion Engineering Company, Inc.**, a newly organized company, took over the properties of International Combustion Engineering Corporation and affiliated companies recently sold by order of the Federal Court. The properties acquired include those of Combustion Engineering Corporation, Hedges-Walsh-Weidner Company, Coshocton Iron Company and Raymond Bros. Impact Pulverizer Company.

Crystalline Structure in Relation to Failure of Metals Especially by Fatigue*

By H. J. Gough**

Extended Abstract by Dr. H. W. Gillett

THROUGH the courtesy of Prof. H. F. Moore, Chairman A.S.T.M. Fatigue Research Committee, we have been privileged to read the complete manuscript of Dr. Gough's Marburg Lecture. The lecture is very extensive and the lecturer could only hit the high spots in his oral presentation. The complete form will duly appear in the A.S.T.M. Proceedings.

Since so many of the papers delivered before technical societies are preprinted, one is prone to read the preprints to get the information as soon as possible, when the printed transactions arrive, to put them on the shelf to be used for reference, thus failing to read what has not been preprinted. If this method were followed, and Dr. Gough's lecture were missed, it would be too bad. No one interested in metallurgy or in fatigue should miss it.

The lecture is itself an abstract of some 10 years of pioneer work by the lecturer and his colleagues, with much reference to the work of others—it contains 175 references—so even an extended abstract can do little more than act as a sign post pointing to the profit to be gotten from a reading of the complete lecture.

Gough's basic desire is to find out more about the mechanism of and causes for fatigue failure, for practical engineering purposes—he is Superintendent of the Engineering Department of the N.P.L.—but to do this intelligently, he has been forced to start from the bottom up. Testing of normal polycrystalline materials could be carried on indefinitely without revealing clearly the various factors involved, so Gough starts with single crystals. He reasons that the properties of a polycrystalline metal depend on the properties of each individual crystal within it, on the boundaries between the crystals and on the orientation of the individual crystals.

This leads him first to a consideration of the properties of the crystal, pretty much through the eyes of the atomic physicist. In fact, the lecture is outstanding for its bringing together of facts and theories of the atomic physics of the crystal in a dispassionate appraisal, wherein the plausibility of some theories and the lack of it in others is made as clear as the evidence will permit. It is all as helpful from this point of view as it is from that of fatigue.

After the crystal itself has been dealt with, he goes on to consider the boundaries, thus leading up to polycrystalline material of engineering importance.

Statistical effects due to the random orientation of individual crystals may result in the behavior of the mass as an effectively isotropic body, approximately obeying Hooke's law and allowing calculations of stress and strain according to the elastic theory.

The individual crystal blocks, however, have marked directional properties and they slip along planes of high atomic population. This fact brings the necessity of considering the atomic structure and even the sub-atomic make-up and properties of the individual atoms.

Since the study of crystal structure by X-ray methods affords some insight into these atomic and sub-atomic properties, it has been utilized as the most powerful present weapon for the purpose, and part of the lecture deals with X-ray evidence, with its tedious but necessary stereographic and crystallographic geometry.

If a single crystal is studied crystallographically so that its directional make-up is known and subjected to repeated stress —torsional stress being usually used for the sake of certain simplifications it affords—a correlation can be made between the direction of application of stress and its results along different directions in the crystal, thus showing what the different atomic planes of the crystal are doing under stress. By putting a metallographic polish on the single crystal fatigue specimen and observing it at different stages in its fatigue history, it is found that slip planes appear and produce little ridges on the surface. By polishing the ridges off and rerunning, the progress of slip and of the effect produced by repeated stress can be traced.

It is found that slip may occur below or at the endurance limit as well as above, and that not only the faces of the slip planes but at least a considerable volume each side of the slip plane is hardened. Although no notable dimensional change occurs in the specimen as a whole, it becomes work-hardened by the minute slip in a fashion quite analogous to cold-working under severe deformation. Strengthening by understressing is therefore definitely defined as a cold-working phenomenon. The crystals have a definite capacity for cold-working of this type and when this capacity is locally exceeded, fatigue damage begins. Of course, if a material, even a single crystal, is not wholly homogeneous, damage may occur locally before the capacity of other locations has been exceeded, and considerable attention is paid to the theories of "mosaic structure" and to other ideas that allege that the crystal has spaced locations of weakness not due to its regular lattice structure.

It is shown that not all parallel slip planes are of equal strength, and that some planes can be over-cold-worked so that damage starts, later to develop into a crack. Strain-hardening comes to an end after it has been carried so far and there is thus a limit to the strengthening of the crystal.

Due to the large number of cycles of stress necessary to reach this limit and to bring the weak-sister planes to their damage points, Gough feels that there is little hope that any accelerated method of showing the endurance limit will be of value.

Beside the effect upon the assemblage of atoms in the lattice, it is also possible that the individual atom is affected and its electronic distribution altered, though positive proof of this has yet to be found.

Going from single crystals to aggregates of two or more crystals so that the effect of the boundary can be traced, it is found that boundaries tend to inhibit slip. Indeed, hardness is found to be inversely proportional to the superficial area of the crystal grain, i.e., the more boundaries there are, the harder the metal and the less readily it slips. Boundary inhibition of slip makes it unnecessary to postulate the presence of "amorphous cement" at boundaries, to account for the boundary effect. That there are minute crystals in the boundary, rather than amorphous material, seems reasonable to Gough.

Lattice distortion is expected to occur at the surface of any crystal, but it is not thought to be necessarily associated with strain-hardening. Lattice distortion is followed by preferred orientation, but preferred orientation is not considered as causing strain-hardening, either.

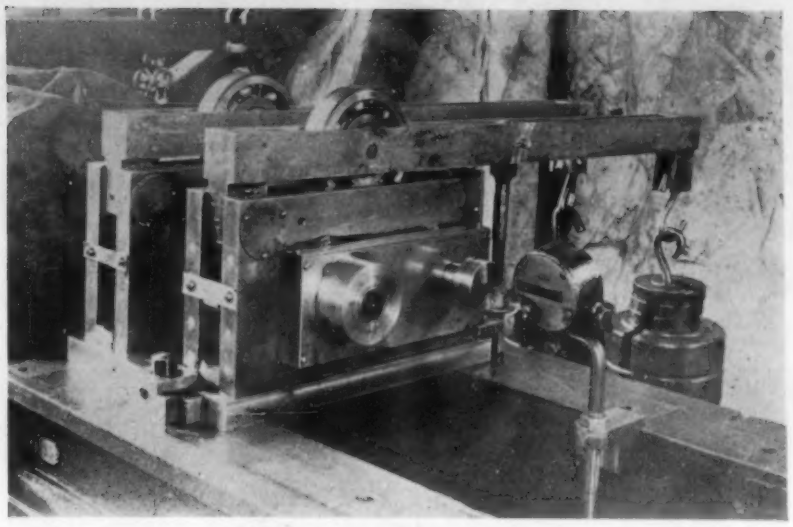
Deformation appears to produce, in this sequence: crystal break-up into small crystals of length about 10,000 interatomic distances, disturbance of electronic arrangement (these two may occur simultaneously or the second may come first), lattice distortion, and finally, preferred orientation. Perhaps it is the electronic disturbance that is the fundamental cause of hardening. This picture of the consequences of slip is then referred to the process of slip and fracture in fatigue, with great care to avoid generalizing from the results of one experiment or from work on one metal alone.

In fatigue failure, cracking starts on an operative slip plane but proceeds through other places that have been generally damaged, generally along the regions of maximum operative shear stress. Very beautiful micrographs illustrate these processes. It is pointed out that α-iron fails along planes of actual maximum shear stress, not maximum resolved shear stress, and

(Continued on page 142)

*A.S.T.M. 1933 Marburg Lecture.

**National Physical Laboratory, England.



New Fatigue Testing Machine

Fatigue Testing

With Simple Test Specimens

By Haakon Styri*

An editorial in *Metals & Alloys,* September 1929, mentioned the desirability of obtaining simpler fatigue specimens to avoid the present high cost of preparation.

Thinking over the various methods of endurance testing it occurred to the writer that a rotating cylindrical ring, loaded radially at 3 points 120° apart, might show possible advantages in testing. A ring could be easily made from bar stock either in high production automatic machines or in the regular machine tools available in a machine shop. Such method of testing has previously been described by Stanton,[1] but was unknown to the writer at the time the present experiments were started. An advantage in using a cylindrical ring is that tool marks and grinding marks will be parallel to the direction of rotation and therefore parallel to the direction of stress. The bending stresses will be maximum in the bore of the ring which is not in direct contact with the rollers transmitting the load.

The thickness of the ring must be chosen so that the superimposition of contact stresses from the rollers on the bending stresses on the outside surface of the ring will not induce fatigue cracking from the outside. A sufficiently thin ring will always crack from the bore where the bending stresses are maximum. The relation between load applied and stresses produced in the bore of the ring has been calculated according to Merriman (Mechanics of Materials, 1916) and Prescott (Applied Elasticity, 1924).

A simple machine built on this principle gave encouraging results and after a few revisions had been incorporated to make the test run smoothly, the machine shown diagrammatically in Fig. 1 was developed. The two lower discs are fixed on arbors which are mounted on ball bearings in the 2 side plates. One arbor is driven from a small electric motor or by belt, the other shaft is driven from the first shaft by an intermediate gear. One of the discs has a groove for guiding the test ring. The top roller is a standard ball bearing with the outer race rotating, the inner race is mounted fixed to a lever which transmits the load at a ratio of 5 to 1.

The reason for this arrangement was the necessity of having 2 driving points in order to avoid slipping and smearing of the ring against the rollers due to the high acceleration and the high speeds used. The small weight of the rotating outer race of a ball bearing for the top roller was of advantage in obtaining low inertia for this driven ring.

The relation between the diameter of the cylindrical ring test specimen and the rollers was chosen so that approximately 15,000 reversals of stress per minute were obtained with an 1800 RPM motor. The dimensions of the machine can, of course, be chosen to suit the dimensions of test specimen that can be obtained and speeds considerably higher or lower than the one selected here can easily be provided.

The specimen now used is 2″ in diameter (o.d.) ½″ wide and ⅛″ thick. When a ¼″ thick specimen was used, the fatigue fracture started on the outside surface but with the thinner specimen, the fracture starts on the inside, at or near the bore surface.

In only a few cases have we been able to catch the specimens just before complete fracture as we have not yet any automatic method of stopping the machine when the specimen fails. In every case, however, the failure is parallel with the axis of the ring and at right angles to the surface.

Some of the early tests were run to investigate the influence of the finish of the surface on the test result. For this purpose, rings made from hot rolled machine steel of about .15 C were tested respectively with machined surface, ground surface and ground and polished surface. The result did not indicate any material difference in life due to finish. The dispersion in life is, however, considerable, and, in all probability, is due to the fact that the rings are tested with stresses transverse to the direction of grain in the ring. The fatigue limit seemed to be in the neighborhood of 31,000 lbs./in.² A sufficient number of test specimens was not available in this test to show this more accurately. However, since this material showed 64.2 Rockwell B (1/16″ ball, 100 kg.), equivalent to 112 Brinell, which would correspond to say 55000-60000 lbs./in.² tensile strength, the ring rolling method gave a normal endurance limit on this soft steel.

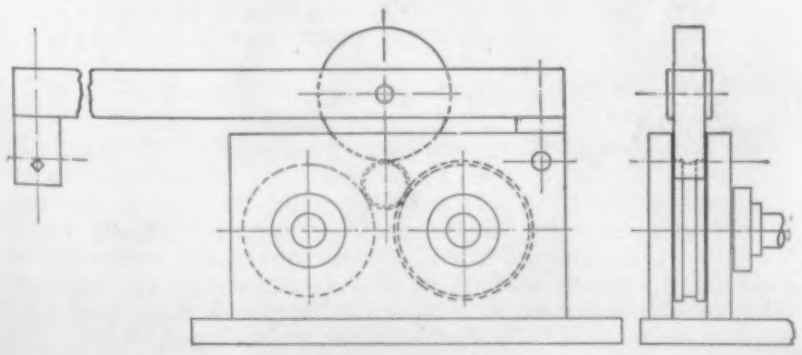
Other tests were later run on bearing steel of about 1½ Cr, 1% C, quenched in oil and tempered to various temperatures as shown in the graph giving the test results. For the annealed condition and for rings quenched and tempered to 600° C. the fatigue limit is very sharply defined but again there is very great dispersion in the lives of the broken specimens, and it is not possible to use these test results to determine the relation between life against load, for stresses above the fatigue limit.

It was not expected that tests on specimens tempered at very low temperatures would show a fatigue limit exactly in proportion to the Brinell hardness, since Moore[2] has shown that above 400 Brinell, the increase in fatigue limit no longer parallels that in hardness. It was, however, surprising to find, for tempering temperatures lower than 400° C., at what low loads the endurance limit was, in these tests.

On the unhardened steel, the Rockwell B hardness (1/16″ ball, 100 kg.) was 85, corresponding to about 160 Brinell or about 80,000 lbs./in.² tensile strength. The steel in that condition would therefore be expected to give an endurance of about

*Director of Research, S.K.F. Industries, Inc., Philadelphia, Pa.

[1]T. E. Stanton. A New Fatigue Test for Iron and Steel. *Journal Iron & Steel Institute,* Vol. 76, 1908, part 1, pages 54-62.

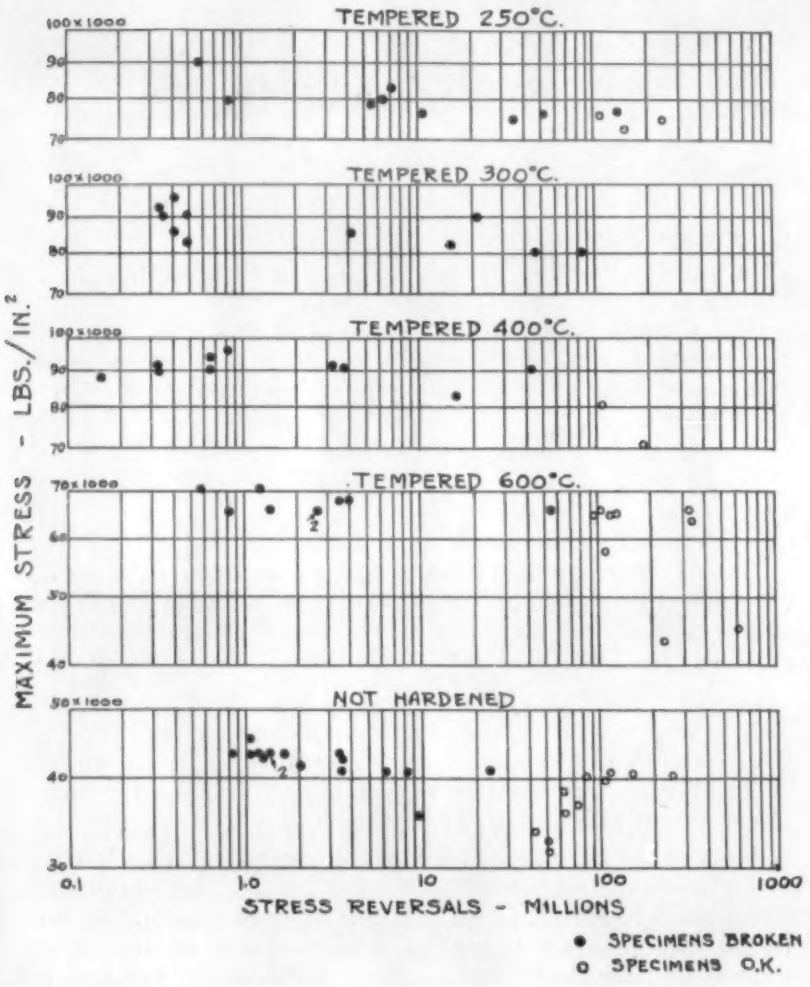


[2]H. F. Moore. The Fatigue of Metals, A Review of Progress from 1920 to 1929. *Year Book, American Iron & Steel Institute,* 1929, pages 304-327.

40,000 lbs./in.², which is just what the ring rolling method does show, again indicating that in soft steels, the method agrees with other types of endurance testing.

But the quenched and tempered 1% C, 1½% Cr steel showed the following results:

Tempering Temp. °C	Rockwell C (150 kg.)	Approx. Brinell Equivalent	Approx. Calculated Ten. Str. lbs./in.²	Apparent End. Limit, Ring & Roller Method lbs./in.²	Apparent Endurance Ratio
250°	58.3	600	300,000	74,000	.25
300°	56.1	570	285,000	<80,000	<.28
400°	50.2	490	245,000	80,000	.33
600°	36.3	335	165,000	66,000	.40



While untempered, quenched steel or that tempered at very low temperatures is known to show not only a low endurance ratio, but also a lower absolute endurance limit than for some moderately high tempering temperature which produces the maximum endurance limit, one would have expected that after the 600° C. tempering, the well-softened steel would show the normal endurance ratio of about .50.

Since the preliminary runs on the unhardened C steel had indicated that polishing the specimen was unnecessary, the quenched and tempered rings in these preliminary tests were run with a ground surface. As the minute grinding marks are parallel to the direction of bending, this finish will probably not account for the low endurance ratio at the 600° C. tempering temperature, or the low ratio in the steel in still harder conditions. But the effect of other surface notches and particularly of slag inclusions and other inhomogeneities in the steel will, of course, be the more marked the harder the steel is.

The results recorded were considered of sufficient promise for evaluation of the quality of steel for our particular purposes to warrant the building of a second machine, and tests on these machines will be continued to throw further light on the problem.

The present test method is being developed with the purpose of investigating both quality of steel and effect of heat treatment, and it was considered an advantage that such part of a bar could be tested as would be subjected to loads f.i. in a ball bearing. The standard rotating beam fatigue testing specimen was not considered adequate for this purpose.

The surface actually stressed to the maximum in a rotating beam specimen with the usual radius of curvature is very small. In the ring rolling test, the whole bore of the ring is under test. If there are occasional imperfections in the steel that lower the endurance and in such number that only one rotating beam bar out of say 5 would contain such an imperfection, one result out of 5 will be low, and we may miss getting this single low result unless we run all 5 bars. If we assume the stressed area of the ring to be only 5 times that of the ordinary bar, one ring would contain one such imperfection and it will fail at a correspondingly low stress.

Less testing should therefore be required to evaluate the quality and uniformity of the steel when the ring method is used.

The collaboration of Mr. W. F. Titus is gratefully acknowledged.

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Failure of Metals Especially by Fatigue

(Continued from page 140)

that the hexagonal metals like zinc both slip and twin, while face centered rhombohedral lattices, like antimony and bismuth, show twinning and cleavage but no slip.

It is concluded that the essential characteristics of fatigue failure of polycrystalline metals are substantially the same as those of single crystals. Differences are those of degree, classifiable as modifying influences, e.g., those of the boundaries. An interesting observation was that in fatigue tests of polycrystalline aluminum a decrease in density occurred, such as is found on cold-working, but no change in density was produced by repeated stress when the same metal was converted to a single crystal and tested. Hence the change in density is wholly associated with the crystal boundaries.

All failures of crystalline materials must ultimately be correlated with cohesive forces. Gough's discussion of problems of atomic forces in the light of so practical an engineering matter as fatigue failure and his orienting of the work of his colleagues who are atomic physicists so as to throw light into the corners that are still dark, and to find out the things the engineer really needs to know, is surely a fruitful method of utilizing atomic physics.

Gough's lecture is "strong meat," containing much of crystallography, computation of shearing stresses, etc., that is hard reading to follow in every detail. Yet, one can pass over those portions, and still find plenty to grasp and appreciate. Not the least will the reader appreciate the fact that an engineer is in process of interpreting the highbrow generalities of atomic physics into definite engineering terms, even though the interpretation is still far from complete.

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A. W. Mace, formerly Assistant to E. P. Thomas, V. P. United States Steel Corp., has been appointed Assistant to the President of the Ludlum Steel Co. to supervise the administration of the Iron and Steel Industry Code throughout the Ludlum organization.

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Reservations in the 15th annual National Metal Exposition, which opens in Convention Hall, Detroit, on Oct. 2, are now far in excess of the total space used at the Buffalo show last year, W. H. Eisenman, secretary of the American Society for Steel Treating, has announced. Matching the quality of this year's Metal Exposition are the technical programs planned by the A.S.S.T. and the other societies participating in the National Metal Congress. These societies include the American Welding Society, the American Institute of Mining and Metallurgical Engineers (Institute of Metals and Iron and Steel Divisions), and the Wire Association. Thirty papers have been tentatively placed on the A.S.S.T. program, of which 21 will be preprinted. Details of the other programs will be announced shortly.

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The Extension Division of Brooklyn College, College of the City of New York, offers a new course in The Principles of Electrochemistry and Photochemistry by Dwight K. Alpern, Ph.D., Electrochemical Engineer. The course will consist of 15 weekly lecture-demonstrations of two hours each, beginning on Friday, September 29th, 1933, at 4:10 o'clock, in the Department of Chemistry at 80 Willoughby Street. The time of subsequent meetings will be decided upon at the first session.

Göransson's Contribution to the

Bessemer Process

MR. B. F. SHEPHERD suggested that, in line with the various articles on metallurgical history, some comment on the important part played by Göransson in the development of the Bessemer process might be obtained from his grandson, K. F. Göransson, the present President of the Sandvik Steel Works.

The published data on the contributions of Bessemer, Mushet and Kelly to the development of the converter process seldom bring out the services of Göransson in this connection. They are recorded in an article by E. F. Lange entitled "Bessemer, Göransson and Mushet: a contribution to technical history" in Manchester Memoirs, vol. lvii, 1913, No. 17, with which it is probable that few metallurgists are conversant. This article brings out the fact that Bessemer's first experiments happened to be made on a pig iron of suitable composition for the process, but when he tried to demonstrate the process at iron-works which were considering the purchase of the process, the experiments failed to work, the method was appraised as a flat failure, and Bessemer was temporarily discredited. Meanwhile, Göransson had acquired the right to operate under Bessemer's patent and was experimenting with it. While he had sufficiently low phosphorus iron to start with and was stopping the blow so as to catch the carbon coming down before all manganese was eliminated, thus operating under conditions similar to those of Bessemer's successful experiments which Bessemer could not duplicate, he, in turn, had difficulties from entrapped slag. With dogged determination he kept at it, altering one condition after another in proper research fashion, until he finally hit upon a suitable set of conditions and was able to put the process into commercial practice and sell the steel so made. Göransson then visited England and put Bessemer on the right track.

G. F. Göransson

Bessemer was then able to import suitable pig irons from Sweden and operate without addition of ferromanganese or spiegel. Only then did Bessemer's own operations get out of red ink, but huge profits were made thereafter. In order to utilize British ores, the Swedish process was finally modified and manganese added, but the interlude, in which Bessemer followed Göransson, put the process on its financial feet. Most metallurgical books dealing with the converter process indicate that the Bessemer process did not operate successfully in practice till final additions of manganese were made, ignoring the period in which the ability of the Swedish iron master to overcome mechanical difficulties and to perform the ticklish job of stopping the blow at the right point, saved the day for Bessemer.

The following letter from the grandson of G. F. Göransson should be of interest to our readers who like to look back upon the struggles of metallurgical pioneers.

Editor

Editor—METALS & ALLOYS:

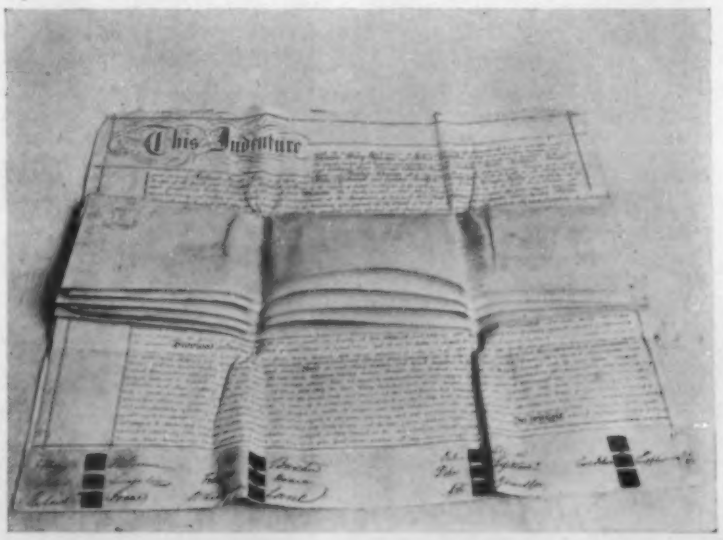
When my grandfather died in 1900 I was a young man of twenty and, naturally, as a youth I heard the story from his own lips, heard about his experiments in the autumn of 1857 and the first half of 1858, when every new blow made was a disappointment with the ingots full of slag and broken to pieces under the hammer.

It is well-known that Sir Henry Bessemer neither in his accounts of the history of his process before meetings of professionals, nor in his monographs, has made any statement as to the part played in this matter by G. F. Göransson. Nor did the latter fight for the honor, at least not publicly, and it is characteristic of his modesty and his aversion to disputes that it was only in 1879, twenty-one years after he had succeeded in solving the problem, that Mr. Göransson wrote the first report for publication regarding his experiments, viz.: in the form of a letter to Professor Richard Akerman of Stockholm. The letter reads as follows:

Dear Sir:

In conformity to your friendly letter of the 2nd instant, I will try to give you, in English, a short sketch of the difficulties I had in commencing with the Bessemer method and how I, at last, overcame them.

My full name is Göran Fredrik Göransson. I bought part of the Swedish Bessemer patent in June, 1857, after a conversation with Sir (then Mr.) Henry Bessemer, and on his promise that he would arrange the necessary plant and send over an engineer for starting the manufacture in accordance with his patents.

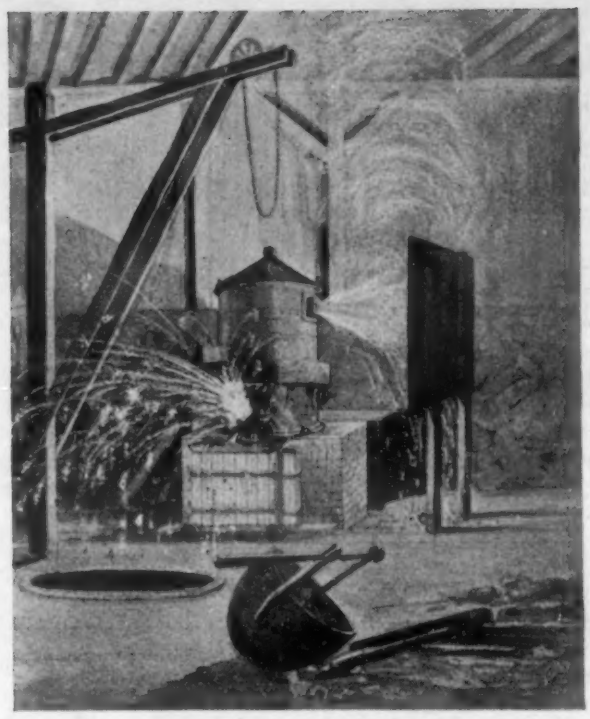


Contract regarding the Purchase by G. F. Göransson of the patent rights for Sweden of Henry Bessemer's invention.

In the autumn he sent over his plant, namely, a converter of his construction and a steam blast-engine constructed by Messrs. Galloway & Co., of Manchester, accompanied by an engineer for conducting the manufacture. We started in November, but we soon found that the converter was impracticable, difficult to handle, and giving no good result. We then constructed a fixed converter on the same principle as the small fixed vessel which Mr. Bessemer used for his first experiments at Baxter House, in London, but, according to Mr. Bessemer's advice, with two rows of tuyeres, six in each, the lower row at the bottom of the converter and the other some inches above; but the result was not good. Mr. Bessemer then advised us to augment the pressure of the blast, and, to effect this, we took away the upper tuyeres and used only the six below, each about five-eighths of an inch in diameter, and we then sometimes succeeded, particularly during the cold, dry, winter days, in getting malleable ingots, but very irregular and generally full of slag. The engineer, not knowing anything more than myself, then left the works.

We tried every possible means of augmenting the pressure of the blast by reducing the diameter of the tuyeres and using smaller charges, as we had reached the limit of the pressure which could be produced by the blast-engine, but all with less and less success, and, on the point of giving up the experiments, I resolved, in spite of all advisers, to diminish the pressure and, instead, use a larger quantity of air. For this purpose we put all the twelve tuyeres in one line at the bottom of the converter, and augmented the diameter of them to seven-eighths of an inch to see what change they would produce. The result was astonishing. The temperature of the

View of the Edske Iron Works at the time of G. F. Göransson's experiments.



Göransson's Bessemer Furnace at Edske, 1858.

fluid steel was very much raised, the slag came up on the top beautifully, the ingots turned out perfectly even in temper, free from slag, and extremely malleable, more so than any iron made on the old process. The first charge with the converter, so arranged, was made on the 18th of July, 1858, and from that date the Bessemer method can be regarded as started.

I sent fifteen tons of ingots to a firm in Sheffield and fifteen tons to Messrs. Henry Bessemer & Co.'s works at the same place, and went over to England in September to have them tried. I found then that Mr. Bessemer had not succeeded, but had to granulate in water the steel he got from the converter and afterwards re-melt it in crucibles. As such a process could not give any profit, the friends who assisted him were losing all hope of success, but they all came down to Sheffield to see my ingots tried before they finally gave up this business. The other Sheffield firm, thinking it their interest not to forward the Bessemer method, got the whole lot burnt at the washwelding, but the fifteen tons hammered and tilted at Messrs. Henry Bessemer & Co.'s works turned out to full satisfaction after having been tried for knives, scissors, razors, other tools and plates.

The result of these trials has led to the further improvement and to the present extension of the Bessemer process, for which Mr. Bessemer and others have done much, but Professor Viktor Eggertz's practical invention to find out the percentage of carbon in the steel has overcome the greatest difficulty then remaining.

Faithfully yours,

G. F. Göransson

Sandvikens Jernverks Aktie Bolag
Sandviken, November 6th, 1879

In this letter he says inter alia: ". . . on the point of giving up the experiments, I resolved, in spite of all advisers, etc." From this sentence we get a glimpse of some very distinctive traits in the character of G. F. Göransson, viz.: his strong will and perseverance in carrying through a task, upon which he had set his mind, and further his resolution and daring. In order to commercialize the Bessemer process, he, in 1862, founded the Sandvik Steel Works, of which he was the leader during nearly 40 years, and in this capacity he had opportunity to manifest these qualities time and again.

He did not belong to that class of pioneers and inventors who do things only to become famous. He was in the first place an industrial leader—I dare say of international standard—not so much of a speculative as of a practical disposition, who spent a great deal of his time amidst his engineers and workmen, and the greatest honor that could be bestowed upon him was that of Sandvik steel being recognized as a product of quality.

Yours very truly,

K. F. Göransson
President of the Sandvik Steel Works
Sandviken, Sweden

June 16, 1933

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Primitive Wrought Iron Manufacture

To the Editor, METALS & ALLOYS:

Wrought iron is an inherently fascinating material—or subject. It is essentially romantic in the tracing of its ancestry to the irons of antiquity. It is intriguing to metallographers; and, of course, there is the time honored question of its shock and fatigue resisting properties.

Ever since reading the interesting article by Curran & Sanford in the January number of *Metals & Alloys* I have been intending to send you a few photographs that I believe would be of interest to readers. These are reproduced from the Report of the Government Geologist of Ceylon for 1904. Just a quarter century ago iron was still being made by these primitive methods and in his report this official put in a plea that Goverment regulations in regard to the cutting of the forests be relaxed to the extent that these native smiths might be able to make charcoal, so that the art should not be lost.

The prints are mostly self explanatory; the furnace, of course, being on the principle of the Catalan Forge of all text books, but I may add the following remarks:

The furnace structures are made of reeds and poles, plastered with clay. The "bellows" consists of skins stretched over hollowed tree sections; there is an inlet in the center that is covered as the "blower" pushes it down with his foot, and open as it is pulled up by the thong and bent pole spring; I cannot say about valves in the tuyeres.

A family consisting of father and three or four sons makes a few pounds (5 or 10) of iron in a day's campaign.

Typical genuine puddled skelp, made by A. M. Byers Co. Wrought iron as we expect it to be. Magnification 100x.

Fig. 1. Iron smelting furnace, Hatarabage, Balangoda; the bellows blower can be seen behind the furnace on the left; the charcoal heap is on the right.

Fig. 3. The iron furnace at work. (The white light is sunlight, not glare from the fire.)

Fig. 5. Steel furnace at Alutnuwara; making steel.

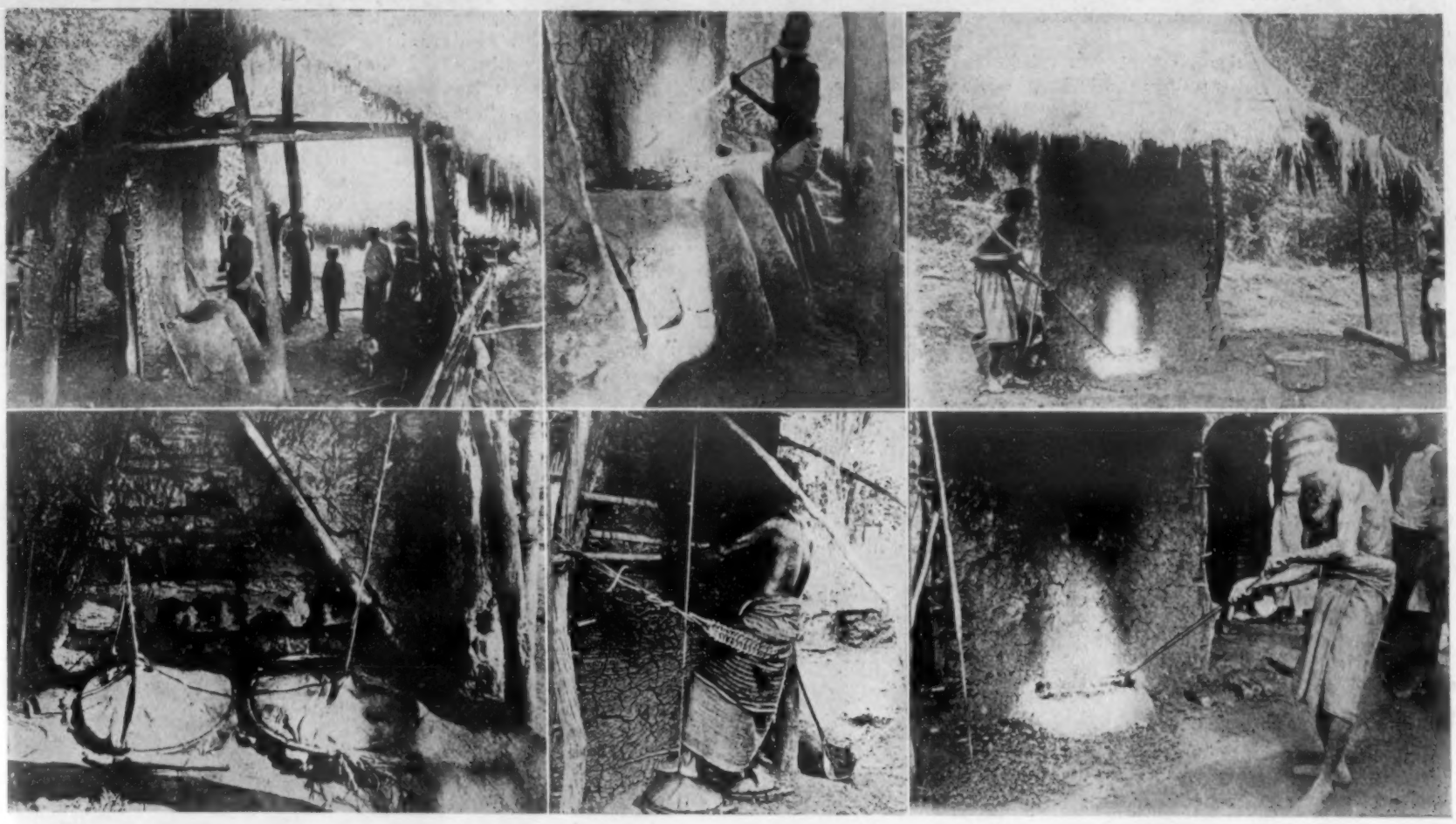


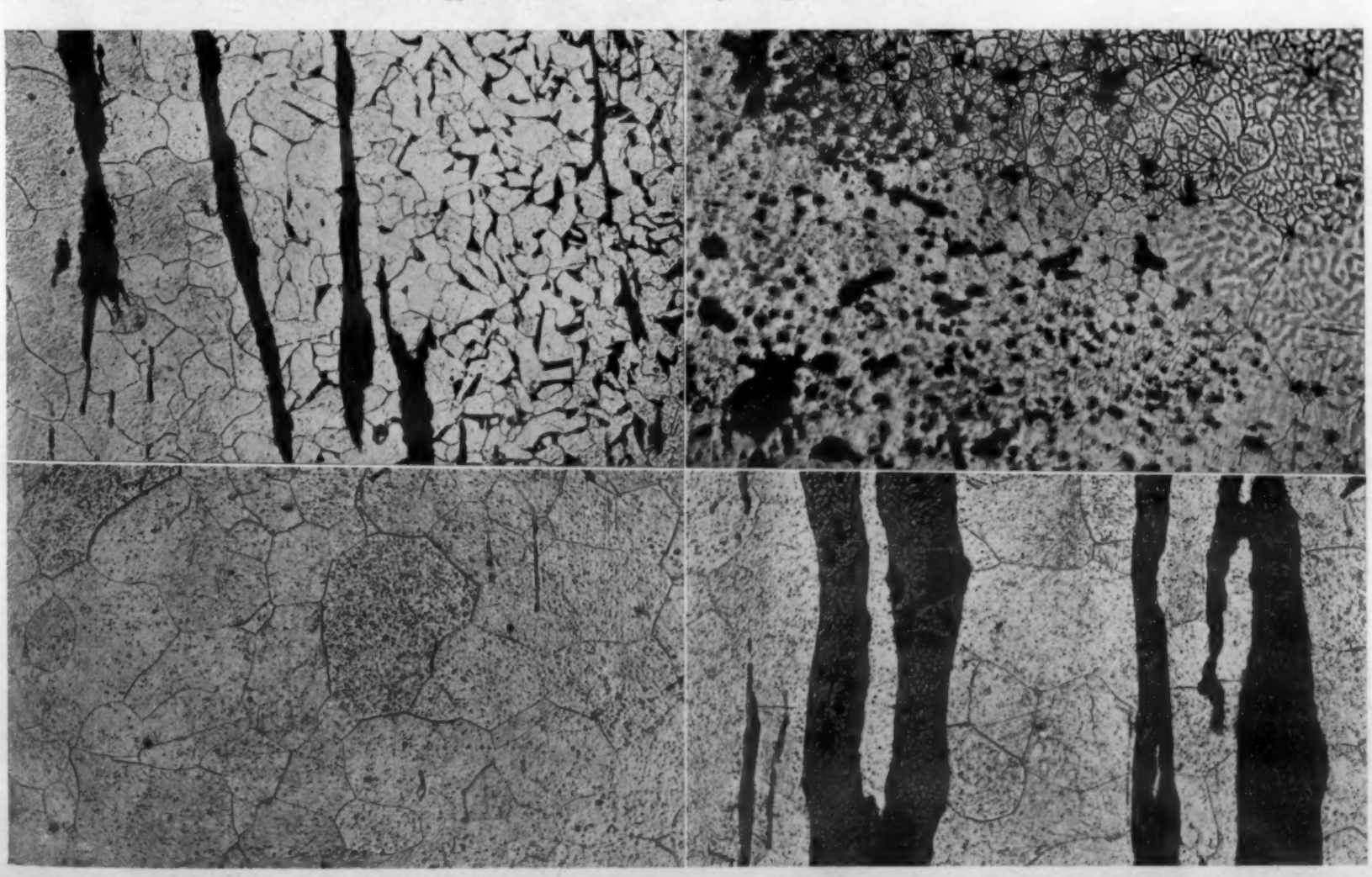
Fig. 2. The bellows. (Iron furnace at Hatarabage.)

Fig. 4. The bellows blower at work. (Steel furnace at Alutnuwara, near Balangoda.)

Fig. 6. Lifting out the crucible of liquid steel.

Fig. 7. Genuine puddled wrought iron muck bar, showing an imperceptible gradation from pure ferrite to a steel-like zone. With this micrograph before us' we might note a point having a bearing on the vexed question of corrosion resistance. In a steel of say 0.10 to 0.15 % C., such as this streak, the rapidly attacked pearlite particles are practically all isolated—they occupy interstices among the ferrite crystals. Therefore after such a steel surface had been corroded for a short time and the surface particles of pearlite had been removed, it would present a uniform ferrite composition to the corroding medium; the elements of electrolysis, so far as the metal itself was concerned, would not be present, and there seems to be no reason why it would continue to corrode any faster than wrought iron—given a steel of reasonable purity and soundness. Magnification 100X.

Fig. 8. Lousy with oxides and stinking with phosphorus, the sample responsible for this micrograph is from a bolt that failed in a derrick and caused the death of two men. The macro-section showed that it was faggotted from miscellaneous scrap. Magnification 100X.



Figs. 9 and 10. Two fields in a *longitudinal* section of a one-inch bar of Swedish iron. The plain polished cross section was almost as clean as steel, with a few clusters of slag. Two severe nick-and-bend tests showed great toughness, though there was no appreciable splitting. Note the dirty-etching character of the ferrite. Magnification 100X.

To make steel, a piece is cut off the crude iron bloom and packed in a clay crucible with charcoal, and covered. It is then heated till melted, the molten state being known by the feel when the crucible is manipulated with tongs—real crucible steel.

I have thought also that you might care for a few micrographs illustrating points made in the January article, in some cases more emphatically. I enclose them herewith, with notes, and if you think they are of sufficient interest to readers, you are welcome to them.

GORDON SPROULE

McGill University
Montreal, Canada
July 17, 1933

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Etching Metallic Surfaces in an X-Ray Tube

Editor, METALS & ALLOYS:

In a paper by U. Nakaya, "Emission of Soft X-Rays by Different Methods with Reference to the Effect of Adsorbed Gases," *Proceedings Royal Society*, Vol. 124, May-July 1929, page 616, it was stated that samples of polished metals such as Fe, Cr, Mn, Co, Ni and Cu were etched by electronic bombardment. The only photomicrograph included in the paper was one of low carbon steel which showed etching at the grain boundaries.

Since Nakaya had studied pure metals only, the effect of the bombardment by electrons on alloys was considered of interest and the following set-up was made. Samples of metal 10 mm. square and 1 mm. thick were polished, screwed into an X-ray target and placed in a Phillips hot wire X-ray tube* which was then evacuated. A wire current of 4.5 amps. gave an electronic bombardment on the samples with a low voltage across the tube. Some of the samples were melted but others showed clear etching effects similar in every way to that obtained with chemical reagents. Oxidation may account for the etching of the specimen on the side towards the beam of electrons but, in many cases, the effect was just as clear on the reverse side of the sample which was screwed down tightly to the copper target. The copper underneath the sample in these cases was bright, i.e., free from oxidation. While it might be thought that the etching is some specific effect resulting from electron bombardment the fact that etching appears on the back of the specimen of such a thickness that electrons would not penetrate clear through, indicates that it is simply a vacuum etching effect due to sublimation at the high temperatures reached.

Western Union Telegraph Co.
June 30, 1933

Frances H. Clark
Metallurgist

Fig. 1. Grain structure of 60-40 Brass subjected to electron bombardment for 4¾ hours. Side towards beam. Magnification 100X.

Fig. 2. Deeper etching of another sample of same 60-40 Brass (Fig. 1) subjected to electron bombardment for 7 hours. Side away from beam. Magnification 100X.

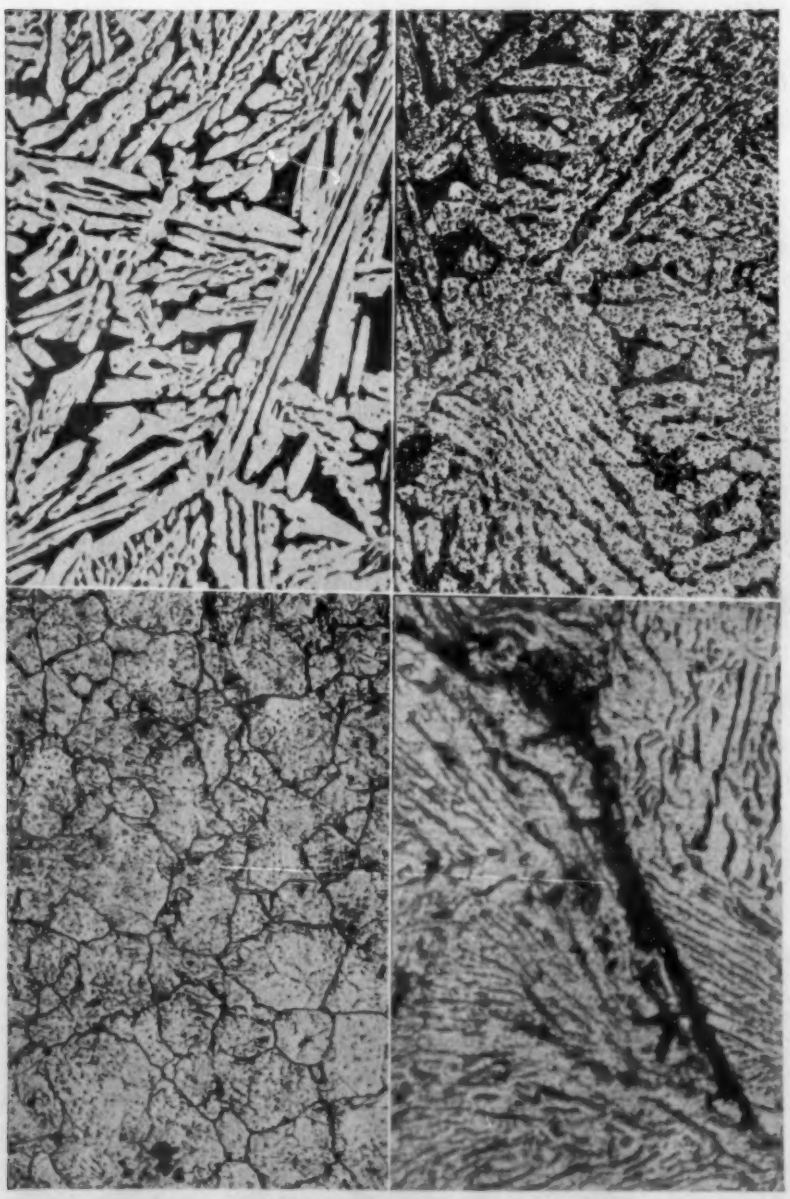

Fig. 3. Pearlite in annealed 0.85 C tool steel subjected to electron bombardment for 5¾ hours. Shows pearlite clearly on side away from beam. Magnification 100X.

Fig. 4. Same as Fig. 3. Magnification 1000X.

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Quenching Oils

Editor, METALS & ALLOYS:

I was interested in the July editorial on "Quench in Oil," as it tallied with my own experience.

No doubt you are familiar with the specifications of General Motors which include Tempering Oils—G.M. 4577-M No. 4578-M. These call for straight mineral oil.

Several years ago after some pretty thorough tests of some proprietory oils, I worked up a specification calling for mineral oil with 3% of Extra No. 1 Lard Oil. The viscosity range was 105 to 120 seconds at 100° C., Saybolt Universal, with Flash Point of 350° F. minimum (Open Cup).

Very truly yours,

ROBERT JOB

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National Weld Testing Bureau

The Pittsburgh Testing Laboratory has organized the first weld testing bureau for qualification of welders.

James W. Owens has been appointed Consulting Engineer and Director of the new bureau.

The bureau proposes to render 6 distinct and separate types of service:

Service No. 1. Reports on the welding processes of manufacturers, fabricators, contractors and firms or corporations, when such reports are necessary to comply with Specifications, Codes or Rules or to obtain insurance on the product or structure.

Service No. 2. Reports on weld specimens which are made *prior to construction* by employees of manufacturers, fabricators, contractors and firms or corporations, when such reports are necessary to comply with Specifications, Codes or Rules; or to obtain insurance on the product or structure.

Service No. 3. Reports on weld specimens which are made *during construction* by employees of manufacturers, fabricators, contractors and firms or corporations, when such reports are necessary to comply with Specifications, Codes or Rules, to satisfy the demands of inspectors, or to obtain insurance on the product or structure.

Service No. 4. Laboratory tests of weld specimens which are submitted to the Bureau for test, and on which the Bureau's representatives have no knowledge of the Process used, or the details involved in the welding of the specimens.

Service No. 5. Inspection of welded products and structures, independently of or in conjunction with our weld testing services, depending on regulations governing the inspection of the product or structure, and on the requirements of clients.

Service No. 6. Investigation of special welding problems, when this type of service does not conflict with the laboratory's neutrality and impartiality.

The first three services are essentially new types of commercial activity based on the requirements for weld testing as embodied in numerous specifications, codes or rules, and recommended good practices relating to new welded construction and to repairs by welding. The primary objectives of these three services, which are featured in a bulletin just released by the company, are to assist manufacturers and other interests to comply with these requirements, and to provide them with a means for satisfying purchasers of welded products, also federal, state, municipal, insurance company, or other inspectors, that these requirements have been met insofar as they relate to the welding process and class of workmanship required.

It is stated that the bureau does not propose to set up weld testing standards of its own, but will use and adhere strictly to those of recognized technical societies, underwriters' laboratories, and other engineering groups. In rendering the first two of its weld testing services, the bureau's representatives will observe welding and testing of specimens in the field and in the plants of its clients.

The bureau claims to be the first nation-wide organization of its type to be established for the purpose of providing a standardized weld testing service. This service will be neutral as regards the welding process, type or make of equipment, or the class of base or filler metal sold or used.